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THE OPEN HEARTH

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THE
OPEN HEARTH

ITS RELATION TO THE STEEL INDUSTRY
ITS DESIGN AND OPERATION

BY

VICTOR WINDETT, S. B.
MEMBER A. S. C. E.

AND ASSOCIATE ENGINEERS OF
THE WELLMAN-SEAVER-MORGAN COMPANY
WITH HISTORICAL SKETCH
BY LATE
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This volume is dedicated to

SAMUEL T. WELLMAN

the father of the open hearth in America and founder of The Wellman-Seaver-Morgan Company, who gave many years of constructive effort to the invention, design and improvement of open hearth furnaces and steel plants.

INTRODUCTION

The purpose of this book is to gather into one volume authentic engineering data relative to the design, construction and operation of open hearth furnaces and the machinery and accessories used in connection with these furnaces. The facts given are based largely on the working data of the engineers of The Wellman-Seaver-Morgan Company. This company is a pioneer manufacturer of steel plant equipment. Its founder, the late Samuel T. Wellman, built the first commercially successful open hearth steel melting furnace in this country. It was put into operation early in 1870. Ever since then, the name Wellman has been associated with the best of steel engineering and metallurgy and the company has been identified with many improvements in the practice of steel manufacture. The company's data have been constantly enriched by intimate exchange of experiences and records with the best practicing steel makers of the present time.

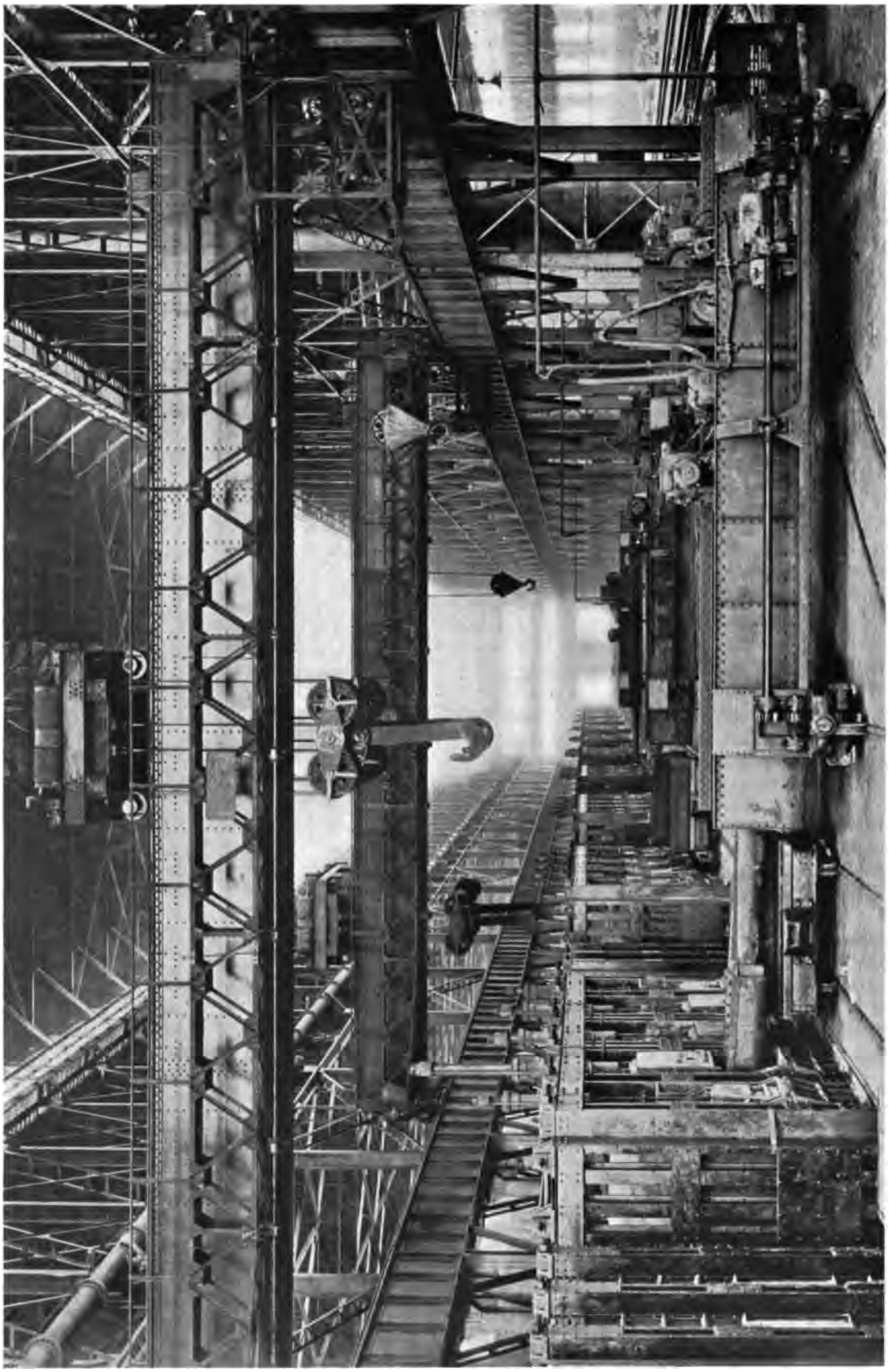

Figure 1—THE CHARGING SIDE OF A STEEL MILL

This view shows low type charging machines, charging cars and boxes. The over-head electric traveling crane has extra strong and long hooks for carrying steel ladles used in charging "hot metal" into the furnaces.

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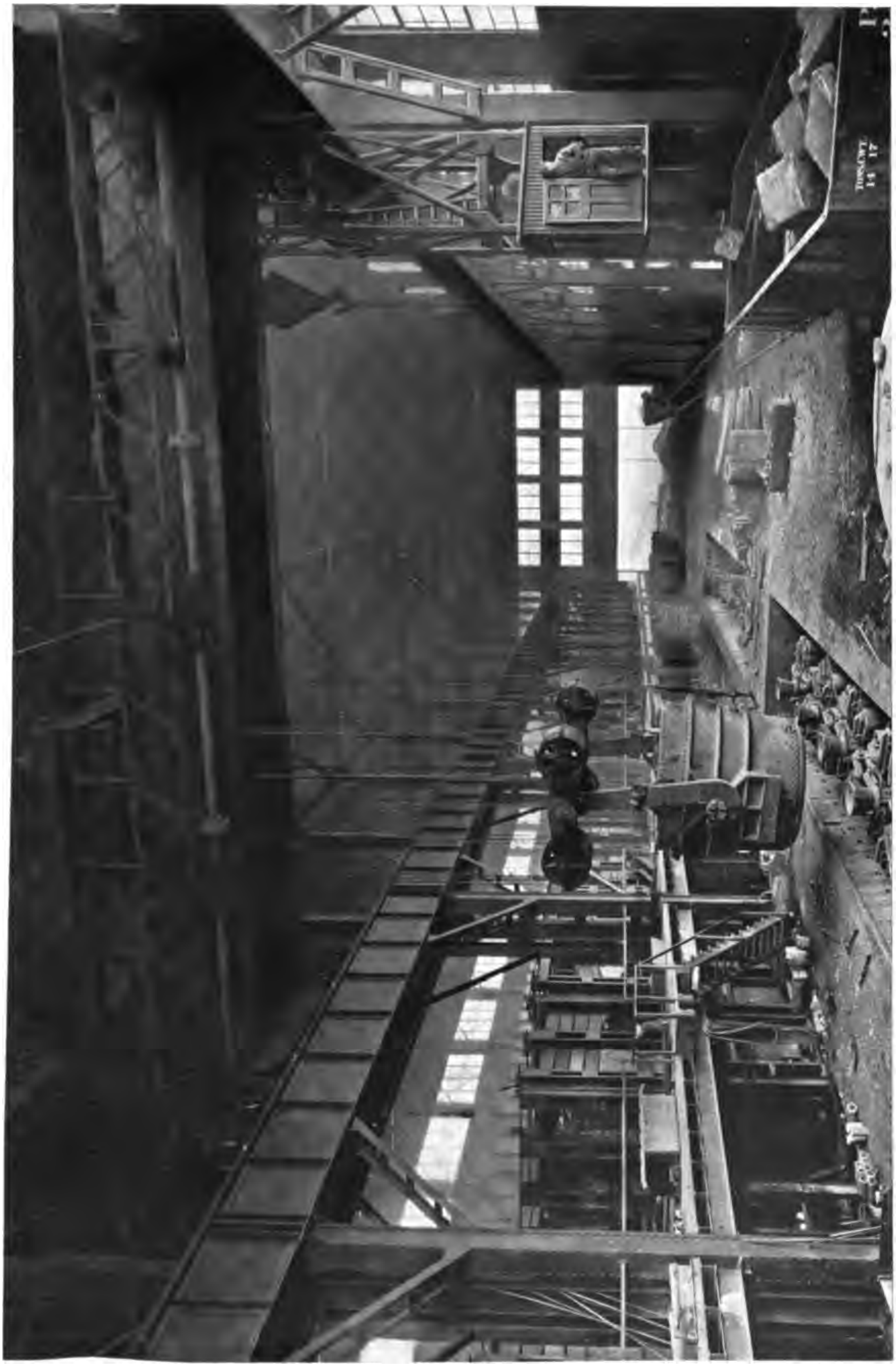

Figure 2—THE CASTING SIDE OF A STEEL MILL.

The steel ladle is carried by an over-head electric traveling crane. The ingot molds for "bottom" pouring are grouped in the casting pit around central pouring funnels, and brick lined down takes.

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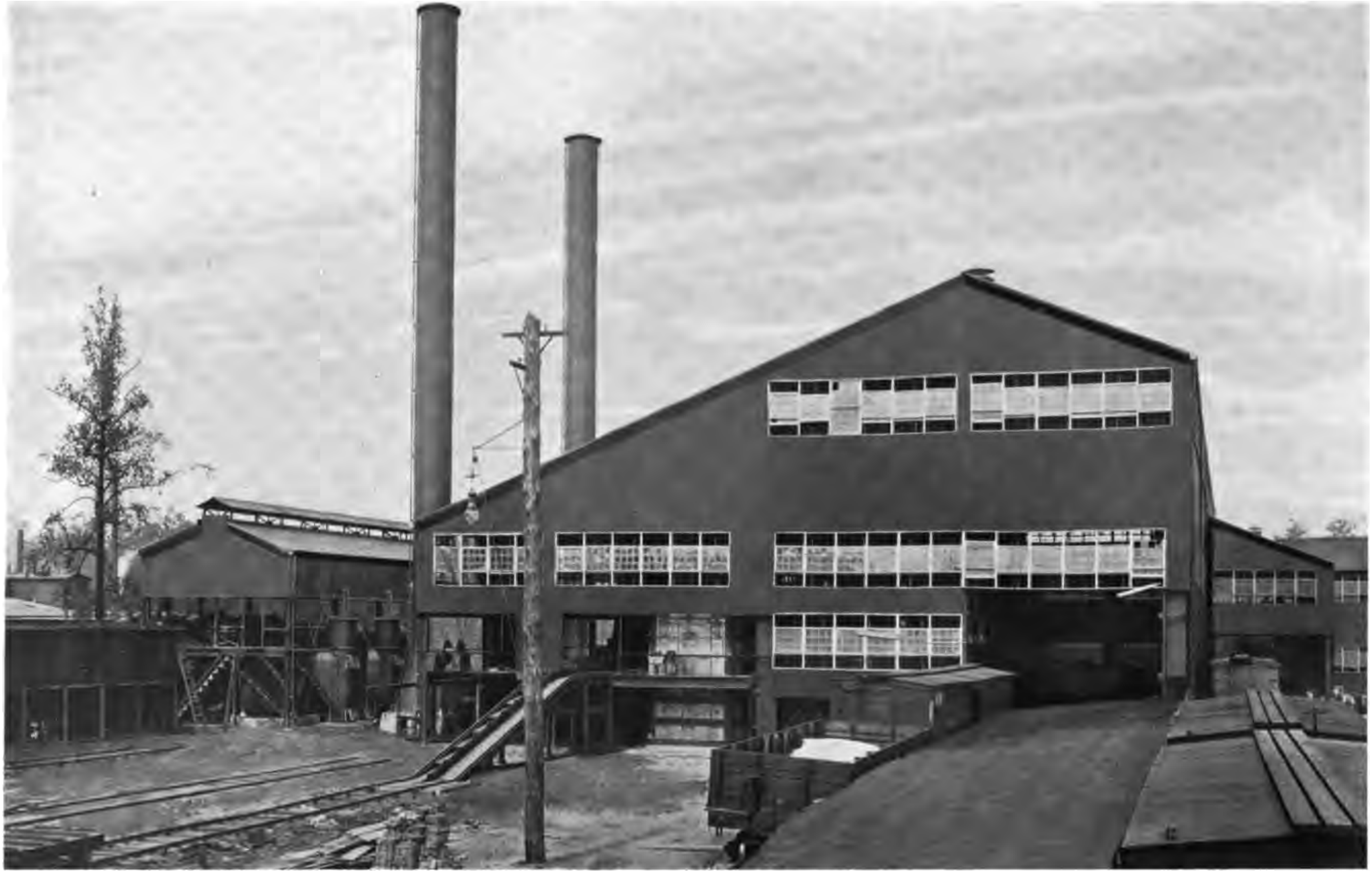


Figure 3—OPEN HEARTH FOUNDRY OF THE ATLANTA STEEL COMPANY, ATLANTA, GA.

It is fully equipped with Wellman open hearth furnaces, gas producers, charging machines, cars and boxes. At this plant the Talbot process was first tried out, Wellman furnaces, being used.

CHAPTER I

Methods of Iron and Steel Making

Iron is extracted from the ore and reduced to pig iron in blast furnaces yielding:

a.—Direct iron castings.

b.—Bessemer pig iron (or hot metal) for the acid or basic Bessemer converter.

c.—Bessemer pig iron (or hot metal) for the acid or basic open hearth furnace.

d.—Foundry and malleable iron.

e.—Spiegel, ferromanganese and special iron alloys.

From these are produced:

1. Wrought iron made from coke or charcoal pig iron in puddling furnaces.
2. Crucible steel made from wrought iron and scrap, in clay or graphite crucibles.
3. Acid Bessemer steel made by blowing air through molten pig iron in acid lined converters.
4. Basic Bessemer steel made by blowing air through molten pig iron in basic lined converters.
5. Acid open hearth steel made on silicious bottom in open hearth furnaces.
6. Basic open hearth steel made on basic bottom open hearth furnaces.
7. Foundry pig iron melted in cupolas or in reverberatory furnaces.
8. Reverberatory furnace iron castings annealed in pots for malleable iron.
9. Electric furnace steel made in either acid or basic lined furnaces.
10. Steel of the duplex process in which the iron is desiliconized and partly decarburized in Bessemer converters either acid or basic and finished in either acid or basic open hearth furnaces.
11. Steel of the triplex process combining Bessemer converters, open hearth and electric furnaces.

Basic Bessemer converters are used to a limited extent in the Southern States.

Types of Open Hearth Furnaces

Open hearth steel, now produced in vast quantities and of high quality, is without a doubt the most important metallurgical product of the present day. The following types of open hearth furnaces and processes are in use:

1. The stationary acid or basic furnace.
2. The tilting acid or basic furnace.
3. The Wellman tilting, acid or basic furnace.
4. The Talbot tilting furnace process.
5. The Monell tilting furnace process.
6. The Surzycki tilting furnace process.
7. The Campbell tilting furnace.
8. The Bertrand-Thiel process, using two stationary open hearths.
9. The Lash furnace with single regenerators for natural gas.
10. The Siemens furnace, and pig iron and ore process used in Europe.
11. The Martin furnace, and pig iron and ore process.
12. The various smaller patented types of furnaces for foundry use.

Description of these processes are given in chapter III page 49.

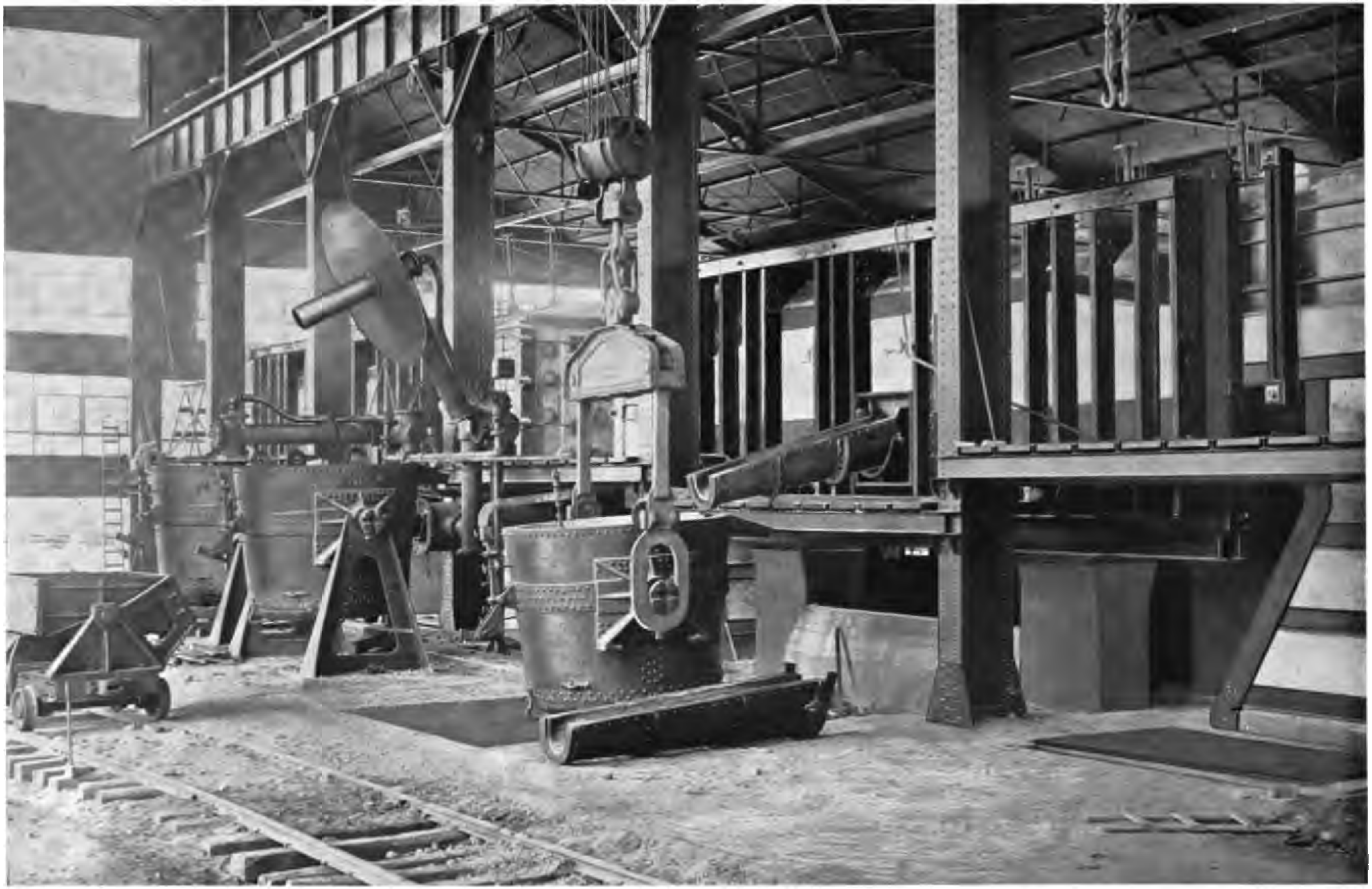


Figure 4—TWO 35-TON ACID WELLMAN FURNACES

This installation is at The Atlanta Steel Company, Atlanta, Ga. Close to the furnaces are the stands where the steel ladles are dried and heated by producer gas burners fitted with heat retaining hoods.

Bessemer Steel—Historical

Crucible Steel

Prior to 1854 steel was made in commercial quantities only by heating bars of wrought iron bedded in powdered charcoal and packed in closed boxes or crucibles. By the absorption of sufficient carbon the iron was changed into steel. The bars were then melted in covered earthenware crucibles and poured into ingot moulds or into moulds for the production of castings. This process was the invention of Huntsman of Sheffield, England, in 1740. The product goes by the names of "blister," "cementation," "cast," "tool" or "crucible" steel. The most commonly used name at the present time is "crucible" steel. The metal is of a high quality, quite free from injurious metalloids, and perfectly homogeneous in character. The cost of this steel is high, due to the small quantity produced, the relatively large labor factor, high fuel consumption and the cost of crucibles, which are expensive and short lived.

The average weight of steel melted in a crucible at one time is about one hundred pounds. In exceptional instances large ingots weighing several tons have been cast by pouring into the mould a great many crucibles in quick succession. On account of these circumstances, the use of crucible steel, as this method is commonly called, is restricted to cutlery, instruments, tools, machinery and artillery, where fine quality offsets high cost.

Crucible steel is stillmade, but in relatively unimportant quantities on account of the introduction of the Bessemer open hearth and electric processes.

Bessemer Steel

In 1854 Henry Bessemer, a steel maker of Sheffield, England, gave to the world a successfully developed process of steel making known by his name. Aside from Watt's invention of the steam engine, no invention since that of printing has so profoundly affected the welfare of the human race as Sir Henry Bessemer's contribution. Bessemer's trials, failures and partial successes culminated in an art so well developed that all improvements made since then have been of operating or technical details and of increased scale of operations. Table No. 91 (Page 331) shows the production of steel in the United States and indicates that the Bessemer process is on the decline:

Process and Chemistry

Bessemer steel is made by blowing air at a pressure of from 10 to 30 pounds pressure per square inch through molten cast iron by which silicon, manganese and carbon in the metal is eliminated by oxidation after which sufficient molten iron rich in manganese and carbon is added to give a steel of the desired manganese and carbon content.

There are two kinds of refractory materials used to line the vessel or converter in which the process is conducted. One of these materials, and in this country the most common one, is ground quartz rock which is mixed in a "pug" mill and moistened to the consistency of damp clay. It is rammed firmly in place on the interior of the converter. This is very largely silica (SiO_2). As the silicon of the iron, undergoing conversion, is converted into SiO_2, there is no chemical reaction between the vessel lining and the SiO_2 from the iron. The vessel lining is subjected only to the abrasive action of the iron and slag during the "blow." The process of making steel in a converter of silicious lining is called the "acid" process.

In the conversion of a high phosphorus iron, the phosphorus is eliminated by adding a basic flux to the charge. This is usually burnt lime, as the addition of limestone or dolomite, which are carbonates, absorb heat in driving off the carbon dioxide. The use of a basic flux necessitates a similar lining to the converter. This is made up in such instances of magnesite, which is used in the calcined form and chemically is the oxide of magnesia. This gives rise to the name of the "basic" process.

The hitherto great abundance of easily marketed low phosphorus iron ores, in the northern part of the United States, has made the acid process the preponderating method used in making Bessemer steel in this country. On account of the greater abundance of highly phosphatic ores in Germany and our Southern states, the basic process has reached its greatest development in these localities.

Iron for Bessemerizing should conform to the following specifications for American practice:

Table No. 1

	Acid Bessemer Iron	Basic Bessemer Iron
Carbon	3.0 to 4.0%	3.0 to 4.0%
Manganese	0.3 to 0.8%	0.2 to 3.0%
Silicon	0.8 to 1.5%	0.5 to 1.0%
Sulphur	less than 0.05%	0.5 to 1.0%
Phosphorus	less than 0.10%	0.2 to 3.0%

In the acid process the conversion of iron into steel is due to the oxidation and elimination of the metalloids of the iron by the oxygen of the air blast. As this leaves the tuyeres and enters the iron, its temperature rises to the point of combination with the silicon in the metal. The combustion of the silicon and of a certain amount of iron immediately at the end of the tuyeres or air passages through the converter bottom brings the temperature up to the combustion point of manganese which then oxidizes and lastly the carbon is ignited. The oxides of silicon and manganese form a slag to which is added the waste from the converter lining. During this part of the process small particles of slag, oxidized iron and incandescent nitrogen are discharged from the converter mouth. When the temperature of combustion of the carbon in the iron has been reached, the carbon burns, forming carbon monoxide gas which on passing out of the converter burns to carbon dioxide with a great luminous flame, which suddenly drops on the complete oxidation of the carbon. This part of the operation is then completed.

At all stages of the "blow" much iron is oxidized near the "tuyeres" where the blast enters the charge. The oxide thus formed is quickly reduced by the silicon, manganese and carbon whose affinities for oxygen at the existing temperatures is greater than that of iron. The only iron loss is a small amount which on being oxidized comes in contact with the lining and forms a silicate of iron, or which reaches the slag at the top and becomes lost in its mass. Even some of the latter oxide is reduced again by the metalloids in case the iron in the slag exceeds a certain amount.

The metal at the end of the blow is a practically pure wrought iron having a percentage of sulphur and phosphorus higher than the original percentages, as these metalloids have not been oxidized and on account of the elimination of the others the net weight is less than at first.

The desired amount of manganese and carbon specified for the finished product of steel is obtained by pouring into the vessel a small quantity of spiegeleisen or ferromanganese rich in carbon.

The English mills had much trouble at first on account of the steel being "lively" or "wild." That was due largely to the oxide of iron and to the gases dissolved in the steel. On the cooling of the metal in the ladle and in the ingot moulds blowholes, honeycombing and piping in the ingots occurred. It was found that when the ingots were reduced to blooms by the steam hammer or by rolling that these blowholes, etc., would not weld solid as their surfaces were coated by a thin film of oxide of iron which is unweldable.

Sir Henry Bessemer overcame this trouble by stopping the blowing when the spectroscope showed a sufficient carbon elimination and then pouring the steel into water whereby it was cooled into small shot or globules. This was remelted in crucibles and cast, making acceptable ingots. This was a poor solution to the trouble as it slowed down the steel mill and ran up the cost of production.

The Swedes were the first to make a commercial success of the Bessemer process, so an English metallurgist, R. Mushet, was sent there to study their practice and find out why they did not have the same troubles as the English from "wild" steel. He found the answer in the composition of the iron used, as given below:

Table No. 2

	English Bessemer Iron	Swedish Bessemer Iron
Graphite Carbon	2.09%	1.42%
Combined Carbon	1.20%	2.99%
Silicon	1.95%	0.97%
Phosphorus	0.014%	.019%
Sulphur	0.048%	Trace
Manganese	0.086%	**3.06%**

He found that the Swedes stopped blowing when the residual carbon was from 0.5% to 1.0% and a considerable residue of manganese was in the steel. The manganese acted as a deoxidizer of the iron oxide in the steel, as well as counteracted the sulphur, which, however, was present in very small quantities.

Mushet returned to England and patented in 1856 the process of adding spiegeleisen to the melted steel. This proved to be the salvation of the Bessemer process, and is always used when operating with low manganese iron.

The manganese is added in the form of spiegeleisen or ferro-manganese. Analyses of these metals are as follows:

Table No. 3

	Spiegeleisen			Ferro-manganese	
Carbon	4.84	5.00	5.66	6.20	6.58
Manganese	10.21	20.40	40.50	70.00	82.00
Silicon	1.21	1.10	1.20	1.14	1.00
Sulphur	Trace	Trace	Trace	Trace	Trace
Phosphorus	.06	.06	.07	.09	0.12
Iron	83.51	73.30	52.40	22.30	10.00

As the manganese content increases, the carbon and phosphorus increase while the silicon and iron decrease.

Other recarburizers than spiegeleisen are used, such as:

Ferro-manganese, an iron alloy of iron, carbon and manganese up to 80%.

Ferrosilicon, a very high silicon pig iron.

Silico spiegel, a very high silicon spiegeleisen or a high manganic ferro-silicon. Its action is much similar to that of aluminum described below.

Carbide of silicon or carborundum. While the other recarburizers are made in blast furnaces, carbide of silicon is a product of the electric furnace. It is superior to the other recarburizers in that a smaller amount is required and that its absorption by the metal causes a rise of temperature instead of a drop as is the case with the others.

Aluminum in small quantities is added as the steel is poured into the ladle and is a most powerful deoxidizer of the steel. It permeates the entire mass of the metal. It increases the solvent power of the metal for gases, so that even after solidification the gas is held by the steel in solution. It prevents segregation and gives sounder ingot tops, thus decreasing the loss through scrap and slightly increases the strength of the steel.

When a small amount of recarburizer is needed it is thrown into the steel ladle.

Otherwise it is melted in a cupola and poured into the converter immediately before pouring the steel into the casting ladle. When the alloys furnish enough manganese but are deficient in carbon, then crushed coke, anthracite or charcoal dust put in paper bags is added to the ladle. In this way an additional 0.1% to 0.2% of carbon is added. This is the "Darby" method of recarburizing. The carbon content of the best anthracite is 44%, the rest being ash, etc.

For mild or low carbon steels, ferromanganese is generally used, carrying about 80% manganese.

When hard or high carbon steel is to be made such as is used in rolling rails, the recarburizer is spiegeleisen of about 20% manganese. These selections are made to secure the desired amount of carbon as well as manganese.

The carbon monoxide evolved on addition of ferro or spiegel always causes a violent bubbling or boiling of the steel. In the basic process this secures an intimate contact of metal and slag, which facilitates absorption of phosphorus by the slag.

Where it is desirable to reduce this boiling, silico spiegel is sometimes used, which contains about 10% silicon.

In the acid process the phosphorus of the charge is oxidized and the resulting phosphoric acid reacts on the oxide of iron, forming phosphide of iron. This phosphide is broken up in the presence of silica, and silicate of iron is formed, returning the phosphorus to the metal in the form of the acid, which in turn is reduced by the manganese and carbon, uniting with its oxygen, leaving the phosphorus to form a part of the resulting steel.

Whereas in the acid process, the combustion of the silicon furnishes enough heat to raise the temperature to that necessary for decarburization, in the basic process this source of heat is absent, as the silicon content of the iron is usually 0.5% or less. Advantage of the dephosphorizing basic lining and slag is taken to charge an iron high in phosphorus, using iron which will run up to 3%. The final elimination of the carbon in the latter part of the blow is called the "after blow."

When the converter is first turned up, the oxygen of the blast is consumed in oxidation of the silicon and manganese forming silica and manganese oxide, and only the nitrogen is expelled from the vessel, carrying with it some few sparks of burning iron and particles of slag. During the oxidation of the carbon, the monoxide of carbon is formed, and as it passes through the vessel with the nitrogen of the blast it ignites on leaving the mouth and burns with an intensely bright flame. This portion of the operation is called the "boil." Owing to the large volume of carbon monoxide gas generated, the boiling of the charge is so violent as to require a reduction in volume of the blast. The conclusion of this operation is marked by a comparatively sudden dropping of the flame.

All of the heat required by the Bessemer process, aside from that of the liquid charge, is supplied by the thermochemical reactions taking place in the converter. At times the action becomes too violent. This is controlled by the steel "blower" admitting a certain amount of steam in with the blast. The absorption of heat by the disassociation of the oxygen and hydrogen of the steam rapidly brings down the temperature to a desired point. Another method of control is the dropping into the converter steel scrap, such as crop ends of billets or rails, which by melting absorb heat and lower the temperature. In case the temperature is too low the vessel is tipped down sufficiently to bring one or more tuyeres to the surface of the metal. This not only raises the temperature by an oxidation of iron but also the carbon monoxide which is formed is burnt inside of the converter to carbon dioxide. A short time of such blowing will raise the temperature to the desired point.

The general characteristics of the Bessemer process as practiced in Sweden, England and America are as follows:

Sweden

Pig iron is used of silicon under 1% and manganese 2.4% and upwards. Recarburizers are not used and the blow is stopped when the required decarburizing is reached. The manganese reduces the sulphur, protects the iron from oxidation, and makes a desirable fluid slag. However, the high manganese produces rapid wear of the converter lining, and also prolongs the blowing time. Therefore, the output of steel is low. A Swedish heat will require 17 to 27 minutes to blow. On account of the high fuel cost in Sweden, the practice was started of using "direct hot metal," i. e. taking the molten blast furnace iron direct into the converter. The converters are small in size.

England

The use of high silicon (2.0% to 2.5%) and low manganese (0.75%) iron is customary. This necessitates the use of a recarburizer. On account of the high silicon the blowing time is long, approximately 15 minutes per blow. The English plants are not built with the expectation of the rapid working and great outputs of the American plants.

United States

Low silicon iron from 0.6% to about 1.2% is used; when operating on cupola remelted pig iron the average silicon is from 0.6% to 0.8%. The blowing time is consequently short, running about 7 to 10 minutes. This low silicon has permitted a number of improvements over European practice, such as:

1. Fast and continuous running, so that neither the iron nor steel stands for any length of time long enough to cool off. The converters and steel ladles are always kept hot, at a working temperature.

2. Small loss of heat by radiation from the vessels and ladles, small loss of heat by the small volume of blast used, small loss by the decreased amount of atmospheric moisture blown through the steel.

3. Decreased time of idleness of apparatus.

4. Decreased scorification of vessel linings and less lost time in changing bottoms.

5. Quick bottom changes possible through efficient design and operation in this department.

6. Blowing with the vessel partly tipped over when cool iron is charged or when the vessel has cooled somewhat during a bottom change.

7. It is the opinion of many metallurgists that a low silicon iron yields a better steel than a high silicon iron.

8. The continuity of operation leads to uniformity of conditions of blowing and an accuracy of judgment on the part of the "blower," such that he can detect a difference in the temperature due to an addition of less than ¾ of 1% of scrap in the metal. This is equivalent to a temperature variation of 24.0° Fahrenheit.

Sulphur as found in the product of the blow exists mainly as sulphide of iron which is distributed throughout the mass as thin films, separating the crystals of iron in the steel. This is the reason for the brittleness or "red shortness" of a high sulphur steel. Manganese has a greater affinity than iron for sulphur and hence when in iron it forms a manganese sulphide, which in part rises to the surface and is broken up again, the sulphur passing off in the blast of waste gases as sulphur dioxide. The remainder of the manganese sulphide found in the steel appears as minute globules instead of the widely extended film of iron sulphide. Its deleterious influence is very much less than the iron sulphide.

The basic Bessemer process is carried on in a converter lined with a basic substance such as oxide of calcium or magnesia. During the charging of the pig iron burnt lime is added. The hot metal used, while high in phosphorus, is low in silicon. The resulting slag is highly basic. The converter lining is of dolomite (calcined magnesian limestone). It is bound together by mixing it with sufficient tar so that it may be rammed in place. The affinity of phosphorus for the basic oxides present is sufficient to eliminate it from the iron. The resulting slag is so rich a calcium and magnesium phosphate as to be serviceable as a fertilizer for farm lands.

The reasons for using a low silicon iron in the basic process are largely to preserve the converter lining as the acid oxidized silicon would rapidly attack the basic magnesian lining, and to reduce the amount of lime which is added as a flux. The reactions in a basic converter are substantially similar to those of the acid process, except that in the presence of a basic slag dephosphorization takes place by oxidation followed by the foundation of phosphate of calcium and magnesium which is a stable compound. The blow is completed when the phosphorus is eliminated. During the dephosphorization there is an oxidation of some of the sulphur.

Bessemer steel finds its greatest use in the production of rails, beams, billets, and plates. When molten steel is poured into cold cast iron moulds, as is the universal practice, the occluded gases in the steel tend to collect into bubbles or honeycombs. These cavities are coated with a film of oxide of iron, in which gases are not soluble, as they are in steel. When the ingots are rolled the blow holes, while flattened out and squeezed together, are not always closed solid by the metal welding together under the pressure of the rolls. Minute flaws are left in the steel when this is the case. This trouble occurs most seriously in low carbon steels, but may be overcome to a great extent by adding silica-ferromanganese or the metal aluminum to the steel in the ladle just before pouring into the moulds. These additions deoxidize the iron oxide and carbon monoxide in the steel and also increase the solvent capacity of the steel for gas, so that the gas actually is dissolved by the metal and held so, even after solidification. Another evil replaces the former one by the addition of silica-ferromanganese or aluminum. This is the tendency of the gas in solution to collect in greatest quantity into the metal last to be solidified. This of course is in the axis of the ingot with a tendency, on account of the light specific gravity of the gas, to rise to the top of the ingot. As the temperature of the steel approaches that of solidification, the solution of gas in the steel becomes super-saturated with the inevitable driving off of the excess gas above that normally dissolved at the low temperatures then existing. This gas collects in the center and forms a "pipe" with an enlarged bubble at the top. A partial remedy for this trouble is to limit the amount of manganese and silicon put into the steel and to cast at a low temperature, so that the gas may be expelled by pouring, rather than held in the "pipe" after it has been expelled by the steel. While blowholes and honeycombing are found most in mild or low carbon steels, "piping" occurs mostly in hard or high carbon steels. Among the methods tried to overcome piping is to fit the mould with a sand top which serves as a reservoir for steel to flow down into the cavity in the ingot as the gas rises. Finally another difficulty is found in steel casting. In cooling, an ingot hardens from the outside towards the center. As the metal cools, the sulphur and phosphorus tend to be expelled by the steel so that these metalloids are found to be much more in the axial part of the ingot, rather than towards the surface. In like manner as the ingots cool last at the top, these substances rise towards the top. By casting the ingot of a greater height than is needed in the rolling mill for the production of the desired number of rails, billets, etc., the defective upper part of the ingot containing an excess of sulphur, phosphorus, and piping may be cut off and rejected, leaving the sound metal for the finished product of the rolling mill.

The use of the Bessemer process to produce steel as a finished material has passed its zenith, but it has found another outlet. This is the development of the triplex process in which the converter is used to desiliconize and practically decarburize iron prior to its further refining in the open hearth and electric furnaces.

Table No. 4

Acid Bessemer Practice

Equipment: 3 12-ton Converters—2 150-ton Mixers—2 Iron Cupolas

	Time of Operation	Total 27 Mos.	
		Tons	%
Charge	Blast Furnace Hot Metal	711,217	66.5
	Cupola Iron—Pig Metal	16,139	15.5
	Cupola Iron—Moulds & Stools	23,357	2.2
	Cupola Iron—Scrap	46,754	4.3
	Cupola Converter Scrap	54,642	5.3
	Spiegeleisen	66,562	6.2
	Ferro-manganese	443	0.0
	Ore	9	0.0
	Total	1,069,123	100.0
Product	Rail Steel Ingots	884,084	82.8
	Soft Steel Ingots	26,939	2.4
	Hard (Billet) Steel Ingots	9,927	1.0
	Total Ingots	920,950	86.2
	Steel Castings	2	
	Ingot Butts	13,664	1.2
	Steel Scrap	12,653	1.2
	Iron Scrap	24,392	2.3
	Conversion Loss—Oxidation of Metalloids, etc.	97,462	9.1
	Total	1,069,123	100.0

Heats—Total and per month 85,062–3150

Ave. No. of Heats per 12 Hour Turn 66. Heats of 12.56 tons charged. 10.83 tons net Ingots.

Casting by crane and ladle, using a circular pit—270° for moulds.

Table No. 5

Acid Bessemer Practice

		Total of 27 Months	
Recarburizers	Ferro-manganese—Per Ton Soft Steel	18.3 Lbs.	
	Manganese—Ton All Steels	32.7 Lbs.	
Refractories and Moulds	Vessel Bottoms—Life in Heats	21.7 Heats	
	Tuyeres—Life in Heats	.9 Heats	
	Ladle Stoppers—Life in Heats	1.9 Heats	
	Ladle Nozzles—Life in Heats	6.2 Heats	Per Ton
	Ingot Moulds—Life in Heats	48.0 Heats	51.2 Lbs.
	Ingot Stools—Life in Heats		8.4 Lbs.
Fuel Oil per ton of Steel	Bessemer Mill	20.3 Gals.	
	Mixers	0.1 Gals.	
	Refractories	0.32 Gals.	
	Ladle and Bottom Drying	1.0 Gals.	
	Ferro-manganese Furnace	.01 Gals.	
	Total	21.7 Gals.	
Cupola Practice	Iron melted per lb. of Coke	9.0 Lbs.	
	Iron melted per lb. of Limestone	21.0 Lbs.	
	Spiegel melted per lb. of Coke	6.8 Lbs.	
	Spiegel melted per lb. of Limestone	17.0 Lbs.	
	Mixture—Iron Cupolas Iron, 84.0%, Steel, 16.0%		

Steel Analysis	Carbon—Soft Steel	0.11 to 0.14%	Carbon—Rail Steel	0.385%
	Silicon—Soft Steel	0.048%	Manganese—Rail Steel	1.06%
	Sulphur—Soft Steel	0.058%	Phosphorus—Rail Steel	0.103%
Iron	Silicon—Winter, 1.49%, Summer, 2.04%; Sulphur, 0.033%			
Length of Blow	During 9 Months Period—10.6 Minutes			

Refractories	Quartz	Fire Sand	Clay	Coke	Ground Fire Brick	
Converter Bottoms	15%	26%	23%	16%	20%	Runner Patching, =½ Cupola Lining, +½ Loam.
Converter Patching	67%	16%	17%			
Cupola Lining	50%	26%	24%			Ladle Lining is Loam or Converter Patching.

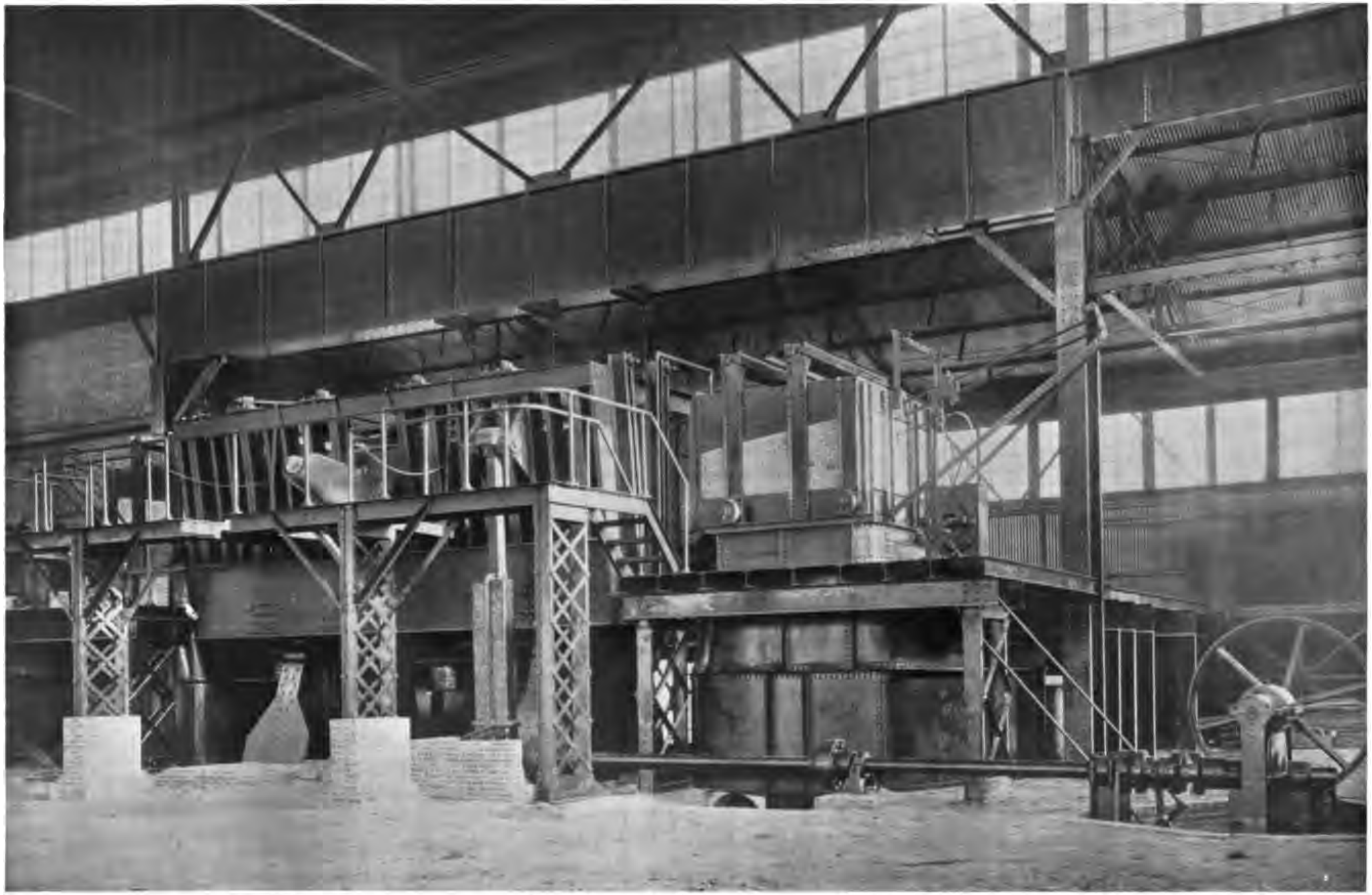


FIGURE 5—TWENTY-TON WELLMAN ELECTRICALLY OPERATED TILTING OPEN HEARTH FURNACE

Installed for the Halcomb Steel Co., Syracuse, N. Y. This furnace was the first open hearth furnace which was used for the Duplex steel process in conjunction with an electric furnace.

CHAPTER II

Early History of the Open Hearth Steel Furnace

The late S. T. Wellman delivered an address as President of the American Society of Mechanical Engineers in 1901, giving the early history of the American open hearth industry. As Mr. Wellman spoke from his personal experience the entire address which follows will be found of value and of particular interest:

"In choosing a subject on which to address you tonight, it occurred to me that I could not do better than take as a topic 'The Early History of Open Hearth Steel Manufacture in the United States.' I am led to do this, first, because I was directly and intimately connected with several of the works where the manufacture was first carried on, and hence can speak from personal knowledge; and, second, from the fact that very little has heretofore been written in regard to this pioneer work. It has seemed to me that you might possibly be interested in a short statement of the facts in regard to the starting of this branch of the steel industry in America, which, beginning in so small a way, is now fast becoming the most important line of the business.

"Before taking up the subject in detail, a few facts as to the inception of the process in Europe may not be out of place. The idea of making steel by an admixture of cast and wrought iron melted together on the open hearth in a reverberatory furnace was first proposed by the French philosopher Reaumur in 1722. We have records of this process being tried several times by different persons during the eighteenth, and the first half of the nineteenth century. In France, a commission appointed by the French Government, under Louis Napoleon, spent a large amount of money on experiments in trying to melt steel on the open hearth of a reverberatory furnace. They succeeded in reaching the necessary temperature, but all of these early experiments failed to be a commercial success, on account of the destructive action of the heat on the lining of the furnace. The heat was obtained only by intensely rapid combustion of coal or coke, which created such a cutting action on the brickwork that the furnace burned out in a very short time, and the quantity of fuel used was so enormous that the process was always a failure from a commercial standpoint.

"The melting of steel in regenerative open hearth furnaces was first proposed by C. W. Siemens in 1861. It was tried in a very small way, by one or two of his licensees, but we have no record of its having been put into successful use. Messrs. Pierre & Emil Martin at the Sireuil Works, near Paris, were the first to carry out the process on a commercial scale, they having built a furnace at their works in 1864, under a license from Siemens.

"Speaking of this furnace, C. W. Siemens, in a paper read before the Chemical Society, May 7, 1868, said: 'It was chiefly intended for a heating furnace, but was so constructed of Dinas silica brick and of such form, that it could be used as a melting furnace.' Messrs. Martin's experiments with this furnace were quite successful, and soon became

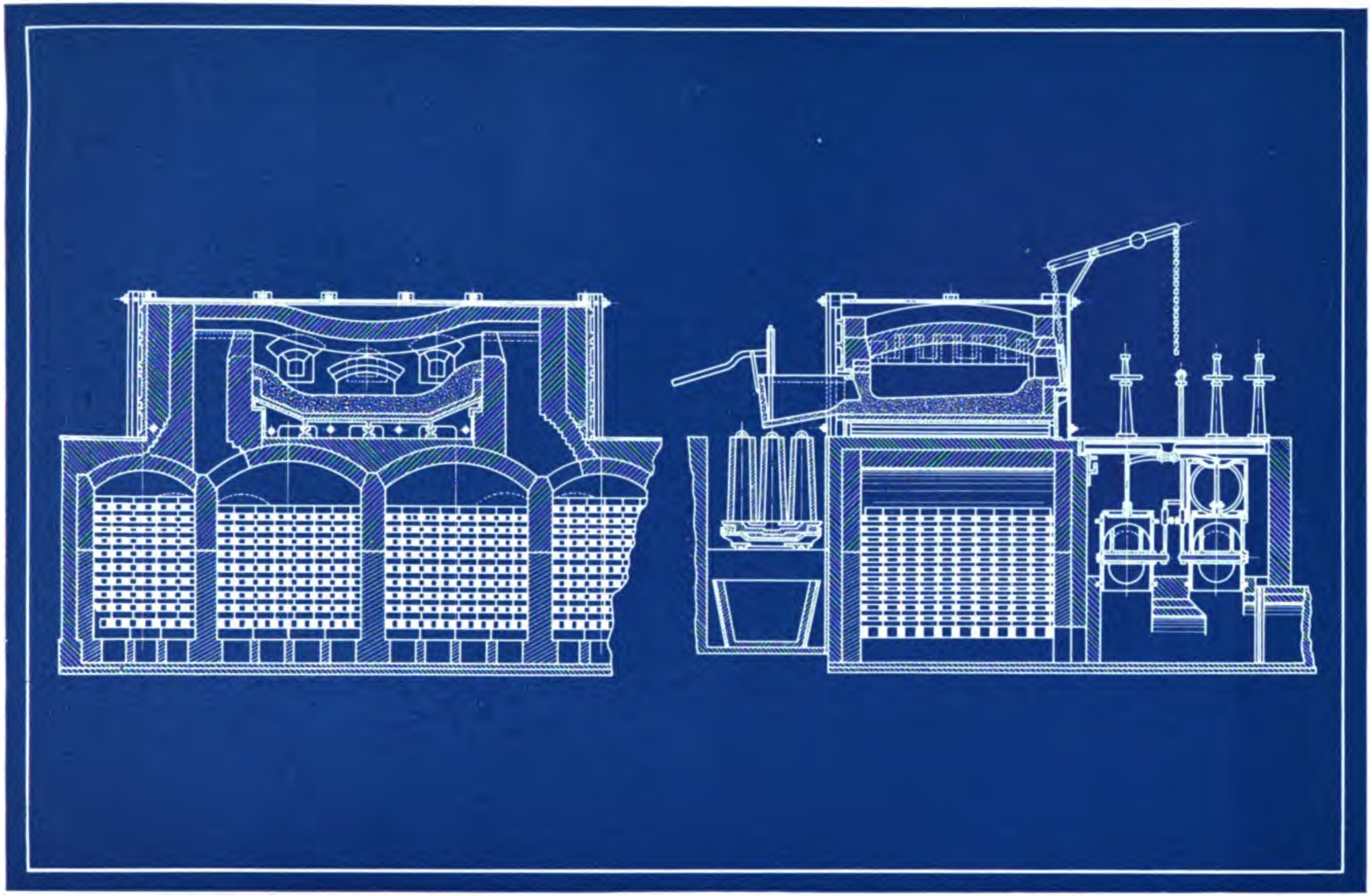


Figure 6—FIVE-TON SIEMENS OPEN HEARTH FURNACE

This figure shows two sections of a 5-ton Siemens Furnace erected in 1869 by the Bay State Iron Works of South Boston, Mass. This company was the first in America to make open-hearth steel, as a commercial success.

known all over the metallurgical world, creating a great deal of interest.

"Among the many iron masters who became interested in the process was Mr. Abram S. Hewitt, who purchased for his firm (Messrs. Cooper, Hewitt & Co., of Trenton, N. J.) the rights in the patents for America. Mr. Fred J. Slade, their engineer, was sent over to France to study the process. When he returned home, Messrs. Cooper, Hewitt & Co. immediately started to erect a small furnace at their works to try the process. This furnace, of only four or five tons' capacity, was put in operation during the fall of 1868, the gas producers being of the regular Siemens type, and built from drawings furnished by Messrs. Siemens' agents in America. I was, at the time, assisting Messrs. Siemens' engineer, Mr. J. T. Potts, who had been sent to this country by C. W. Siemens to have charge of the erection and starting of the first regenerative furnace which was built in this country. This furnace was for the melting of crucible steel, and was built at the works of Messrs. Anderson, Cook & Co., at Pittsburgh, Pa. I was sent by Mr. Potts to Trenton, to assist Mr. Slade in the starting of their gas producers, with which they were having some trouble, thus having good opportunity to see the first efforts to make open hearth steel, and I have a very vivid recollection of some of these experiments.

"Mr. Slade was the only man connected with the works who had ever seen a heat of open hearth steel melted, and as he was not a practical steel man, he probably overlooked some of the important points while watching the manufacture in France. At any rate, everything bad that could happen in the manufacture of open hearth steel seemed to fall to their lot. The best man among the workmen was the melter, who had been an old puddler, or heater, but of course he was unaccustomed to such high temperatures as were necessary to melt mild steel. The first trouble encountered was with the making of good gas. This arose from a too literal interpretation of the printed instructions for running the producers, which had been sent them by Messrs. Siemens' agents.

"When I took charge of the producers, I found they were full to the very top, the coal being some six or seven feet deep; so thick a fire that about all the heat in the bottom of the producers could do, was to drive the moisture from the upper layers. Water and thin tar were running out of the joints through the whole length of the gas flue, or cooling tube, which was of wrought-iron plates, placed above ground. We ran the producers for two days without charging any coal. After about twenty-four hours' work, the producers began to do good service, and we had no further trouble with them. The only difficulty was to get men to attend faithfully to the making of the gas, a very disagreeable job, and one that demands constant watchfulness in order to get the best results.

"Before trying to describe the melting of the first heats, a word or two about the furnaces, and the method of casting. The furnace was a Siemens regenerative furnace, I suppose copied from one in use at Messrs. Martin's works, near Paris. It had a very flat shallow bottom, but there did not seem to be much trouble in getting it up to a fair steel-melting heat. The regenerators seemed to be of ample size, and the furnace fairly well designed for its work, except as to the shape and depth of the bottom, which was entirely too shallow for the quantity of steel it had to hold. On the casting side of the furnace, in front of the tapping hole, was fastened a kind of fore-hearth, called by the workmen, from its shape, "a shoe." In the bottom of this, at the outer end, was placed a firebrick nozzle, in which was fitted a fireclay stopper, by which the flow was regulated. Running parallel with the front of the

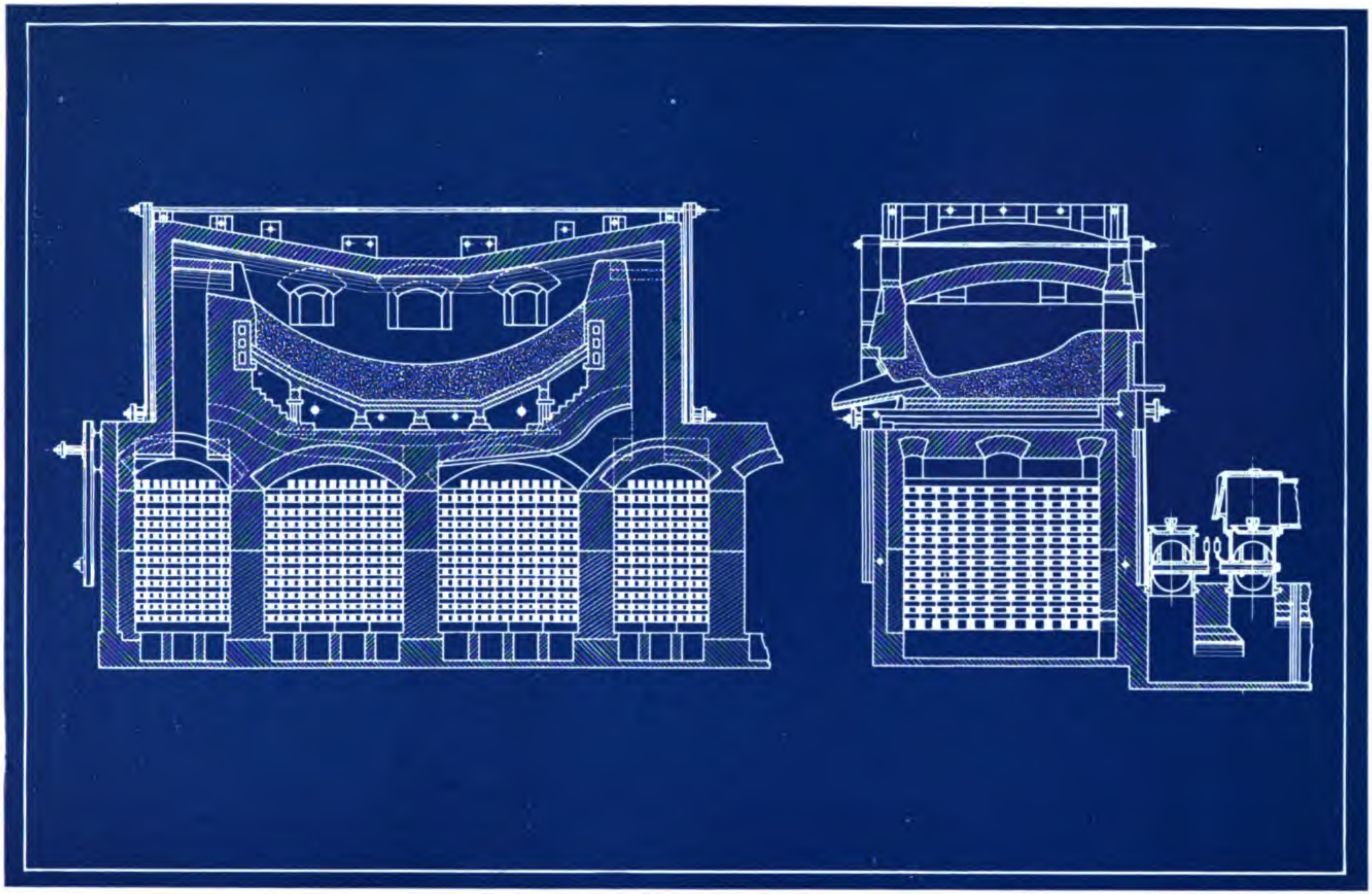


Figure 7—SEVEN-TON OPEN HEARTH FURNACE

This furnace was built in 1873 for the Otis Steel Company. The original plant consisted of two 7-ton furnaces with a regenerative, preliminary furnace for preheating and a regenerative crucible ferro-manganese furnace.

furnace was a narrow-gauge railroad, on which were placed the cars for the ingot moulds, which were arranged for group casting. These cars were moved by a chain windlass placed at one end of the track. In all the heats which I saw made, Franklinite pig iron was used for the bath, and the balance of the heat made up from puddled bars and scrap steel. This mixture should have made good steel, but unfortunately they had no ferromanganese, none being made at that time in this country, and but little, if any, in Europe.

"For recarbonization, they used a small quantity of Franklinite pig; according to my recollection, not more than 1 to 1½ per cent of the weight of the charge. As the Franklinite contained only about 10 per cent of manganese, this gave them a steel very low in that element, with at the most not more than 15–100 of 1 per cent, and often only a mere trace. The result was a steel which was difficult to roll, except at a high temperature. It would stand a welding heat, and a dull red heat, but was yellow short, and any attempt to hammer or roll it at that temperature resulted in the steel going to pieces. If the furnace bottom had been made of magnesite or other basic material, the amount of manganese would have been quite sufficient to have made the steel workable at all temperatures.

"In the first heat at Trenton, when the melter thought, from the small test ingots taken, that the metal was ready to cast, a small quantity of spiegeleisen was added, and when this was melted, a bent bar was driven through the sand wall between the "shoe" and the furnace. When this bar was withdrawn, it allowed the steel to run out and fill the shoe to the level of the steel in the furnace. The stopper being opened, the steel ran out through the nozzle into the moulds. When the first group was filled, the stopper was closed, and the car was moved along until the next group came under the nozzle. In this manner, about one-half of the moulds were filled when the nozzle in the bottom of the shoe began to close up by the metal chilling. It soon closed up entirely, and the car was then moved along until the next group of moulds was in place under the nozzle, when the whole nozzle was lifted out of its place, and the steel then came with a rush for a short time. This operation was repeated until all the steel that was liquid had drained out of the furnace. Only a small proportion made ingots which could be rolled, the larger portion was scrap.

"The great difficulty in these pioneer days of steel making was to teach the melters to maintain the steel at the proper temperature. The margin between the proper casting temperature of the steel and the melting-point of the furnace itself was very narrow, much more so than today, as at that time no silica brick was available, and we were obliged to use clay firebrick for the roof and sides of the furnace. Shortly after the heat which I have mentioned, I saw an attempt made to cast a charge which had chilled in the nozzle so that it could not be started again. By the time the shoe could be taken off, the steel had chilled solid, clear back into the furnace, which was then shut down half full of steel. The next day the furnace was started up again. A quantity of pig iron was added and the steel finally melted, but it was so slow in coming to a steel-melting heat that the carbon was reduced, and several more additions of pig iron had to be made, until finally the furnace was overfilled, making it all the more difficult to get the proper temperature. It was finally tapped, but it was so cold that it chilled in the nozzle and the forehearth, so that when the latter was taken off the steel ran down over the moulds, cars and tracks, welding the whole together, and making a mess that I was afterwards told took two weeks to clean up so that the furnace could again be

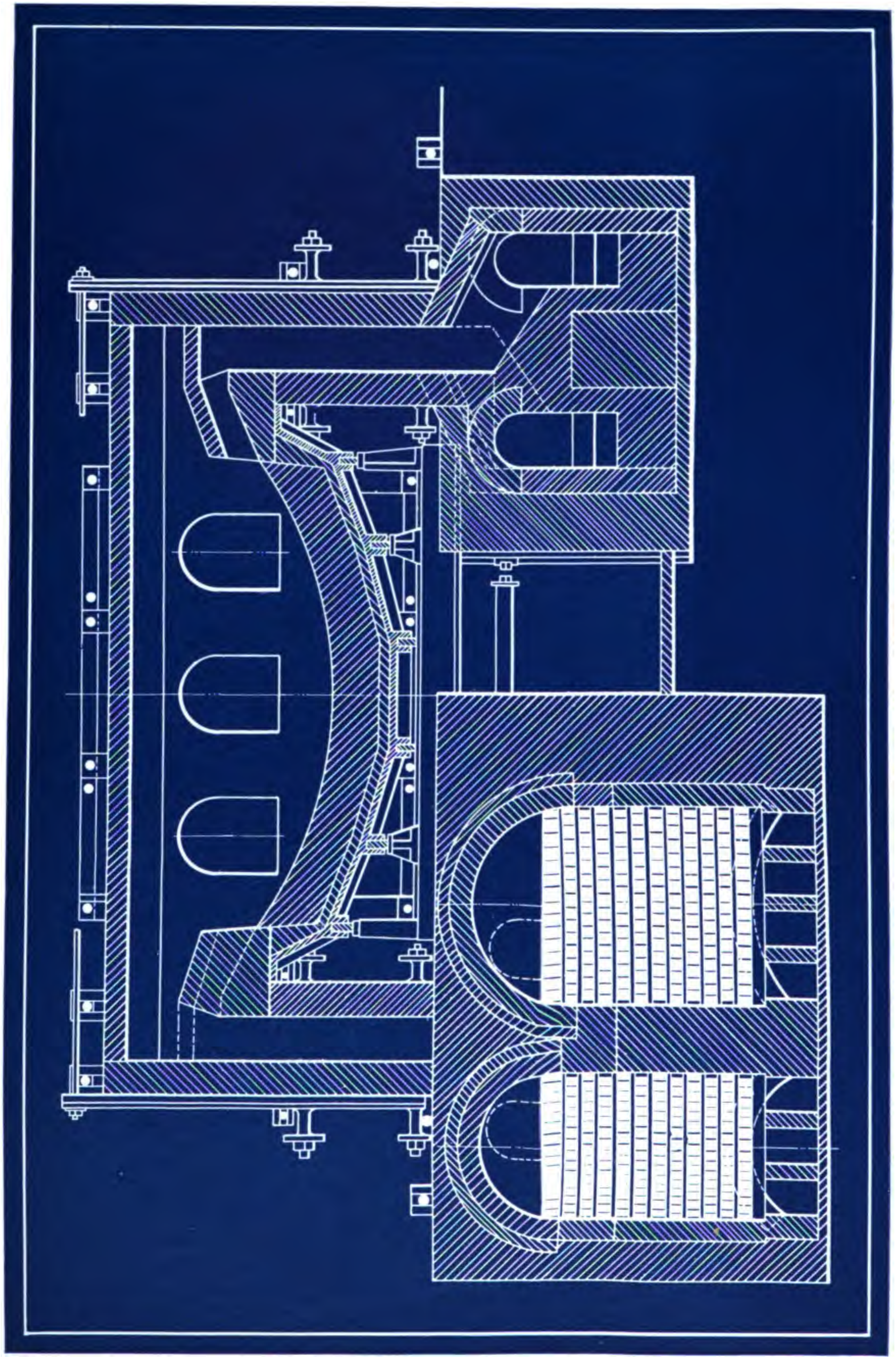


Figure 8—FIFTEEN-TON OPEN HEARTH FURNACE

In 1878 two fifteen-ton furnaces were added to the Otis Steel Plant and in 1881 two more were built. In 1887 two furnaces, the sections of one of which are shown in Figures 7 and 8, were built.

started. These are only examples of the difficulties and rough experiences which were encountered in these initial trials, and it was no wonder that poor Mr. Slade was discouraged.

"As is very often the case, this experiment was not very profitable to the pioneers, Messrs. Cooper, Hewitt & Co. The furnace was operated at intervals for a year or two, but was finally abandoned, and the manufacture stopped, as it was not a commercial success, though those who saw the experiments were able to profit by them and avoid many of the difficulties encountered in them.

"The second works to make open hearth steel in America, and first to make a commercial success of the manufacture, was The Bay State Iron Works, of South Boston, under the superintendence of Mr. Ralph Crooker. Mr. Crooker was an iron master of the old school, and at the time of my association with him had been connected with the management of iron works, in one capacity or another, for over fifty years.

"The Bay State Iron Company had been manufacturers of iron rails for many years, but about this time the advent of steel rails had induced them to experiment in the manufacture of steel-headed rails. Their first experiment was with puddled steel, which was used in the head of the rail, in place of the hard wrought-iron which had generally been used for that purpose. As this did not prove to be a success Bessemer steel ingots were brought from Troy and rolled into bars, which were used in the pile to form the head of the rail. This also was unsuccessful. Bessemer steel as then made was found to be very irregular in quality, and sometimes impossible to weld. At this stage Mr. Crooker's attention was called to the experiments which were being made in the manufacture of open hearth steel at Trenton. He visited the works, and after watching the process for some time, became convinced that with a properly constructed furnace, and the use of ferro-manganese a good weldable steel could be made. He tried to make some arrangements with Messrs. Siemens' agents to supply him with plans for a furnace such as he wanted; but failing in this, he sent for me, I having left Messrs. Siemens' employ several months before this. I soon came to terms with him, and in a few weeks we had the plans well in hand, and started the construction of the proposed works.

"The erection of these, started in 1869, was completed in a few months, and they were put in operation early in 1870. The plant consisted of one furnace of a capacity of five tons, two sections of which are shown in Fig. 6, the necessary gas producers were also built, as well as a coal-fired preheating furnace, and several anthracite crucible steel-melting furnaces for the manufacture of ferro-manganese. The melting furnace was a very powerful one for its size, sharp and quick in its working. The arrangement of ports as shown in the drawing, with several small ports, side by side, and thin division walls between them, gave a very good mixture of gas and air. These thin walls were only 4½ inches thick, and often burned through, which necessitated very frequent repairs; otherwise the furnace was all right, and many furnaces have been built since that did not work as well as this one. The bath was made much deeper than the one at Trenton in proportion to its size; the metal was cast through a forehearth in much the same manner as at Trenton, but the ingot moulds were carried on a large turn-table resting on conical rollers, which was turned by a steam engine through the medium of bevel gearing. This made a very good arrangement and as it was well designed and built, it gave no trouble in operation.

"The melter was a skilled heater who had been in the employ of the Bay State Company for many years. He was a man of most

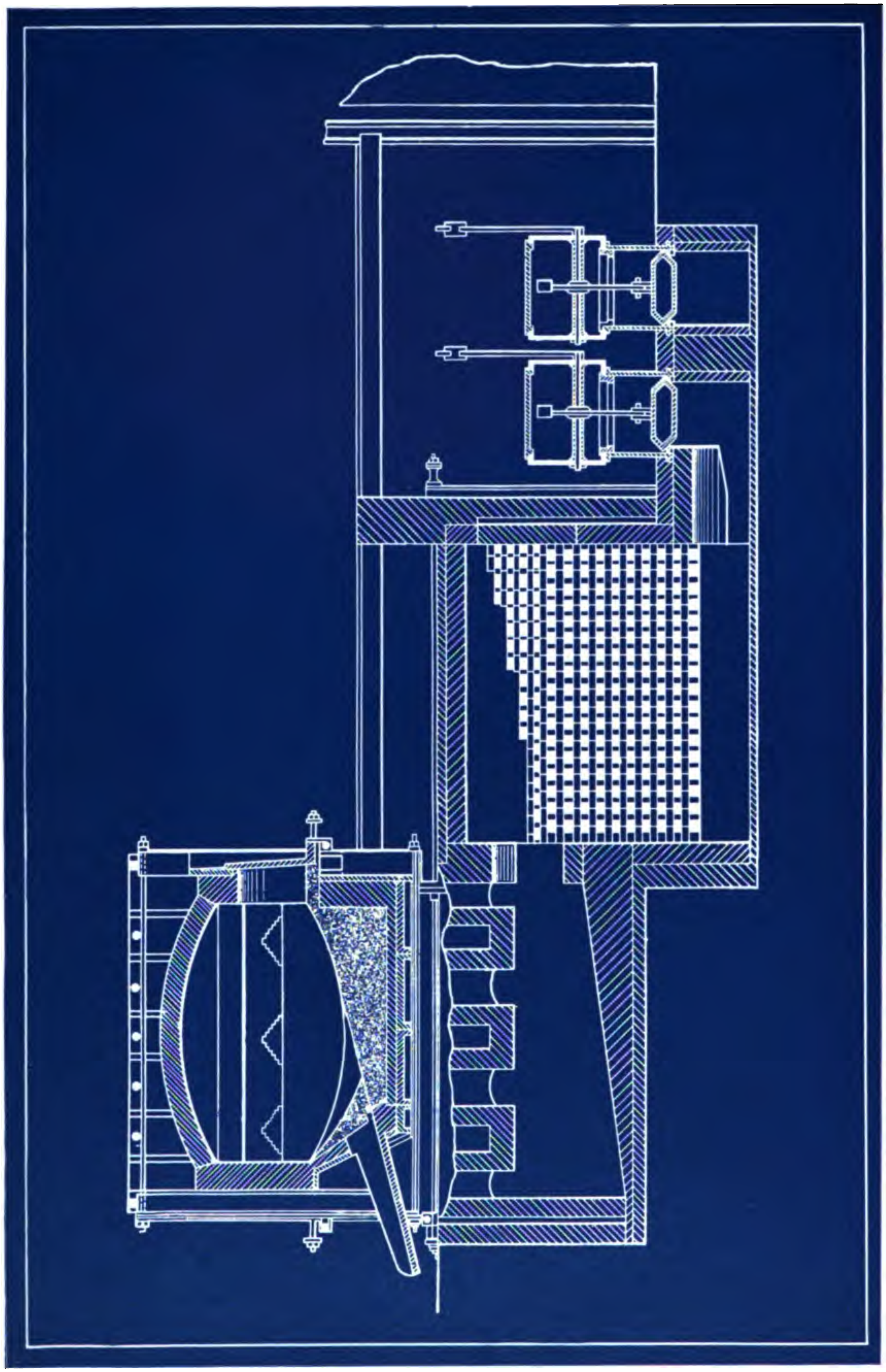


Figure 9—LONGITUDINAL SECTION OF 15-TON FURNACE

This is the first furnace in which the regenerators were placed under the charging platform instead of under the furnace. It was built for the Otis Steel Company of Cleveland, in 1887.

excellent judgment, ambitious, faithful, and conscientious in his work. Having had the advantage of spending a few weeks at Trenton, watching the furnace in operation, he was able to start up the Bay State furnace without much trouble, and soon became a first-class melter.

"The Bay State plant started off with one very great advantage over that at Trenton, in that they had ferro-manganese to use for the final additions in the process. As this could not be purchased at that time, we were obliged to make it in crucibles, which was very expensive, but, as the quantity used was small, the expense did not amount to much per ton of steel. The ferro-manganese was made by reducing black oxide of manganese in crucibles, with charcoal and lime at a very high temperature. When nearly, or quite melted, spiegeleisen or Franklinite pig iron containing about 10 per cent of manganese, was added to the melted manganese in the crucible, and when the whole was thoroughly melted, it was poured into flat moulds. Most of this ferro-manganese contained 35 to 40 per cent of manganese, not very high when compared with the 80 per cent product which is turned out of the blast furnaces in these days, but it answered the purpose, and by its use we were able to make steel of from .10 to .15 carbon that was perfectly malleable at all temperatures. This was a very important advance over the first experiments at Trenton.

"The first steel was made from a mixture of puddled bar made in the Bay State Company's furnaces, with some scrap steel, melted in a bath of English West Cumberland hematite pig iron, and was rolled into bars about 7 inches wide by 2 inches thick. This bar of steel was used for the top of the rail pile, and formed about one-quarter of its weight, the remainder of the pile being made of old iron rails, the weld being apparently as sound as if it were iron on iron. Quite a large quantity of rails was made in this manner and put into use; but the day of "weldless steel rails" had come, and while the steel-headed rails gave better results as to wear than those of iron, they did not begin to do as well in that respect as those made of solid steel, and besides were inferior in strength and stiffness, qualities which had as much to do with good-wearing results as mere difference in hardness of the head.

"It soon became apparent to the Bay State Company that the steel-headed rail was a failure, and that they must look to some other outlet for the product of their steel plant. They were large makers of iron plates as well as rails. Their flange plates had a good reputation, but were costly to make, being puddled from charcoal pig iron. Added to this expense was the tremendous loss from blistering, the average being from 40 to 50 per cent, that amount of plate being cut up and worked over again, making a very serious item of cost. These troubles, and the fact that some very good flange and fire-box steel had been made in Pittsburgh in crucibles, induced them to experiment in the manufacture of soft-steel plates, rolled from ingots made in the open hearth furnace. The first were made from their own bars, puddled from charcoal iron; but this was not satisfactory, as the iron contained too much phosphorus. After quite an amount of experimenting, a small quantity of steel was produced from blooms made in the Lake Champlain district, direct from the ore in the old-fashioned Catalan forge. The result was most satisfactory; a beautifully soft, ductile steel was produced that was perfectly malleable, hot or cold; plates rolled from it never showed a blister, and seldom defects of any kind, and most satisfactory of all was the fact that it could be produced much cheaper than the best iron flange plates. A great many samples of this plate were sent around to different customers, and the company very soon secured a large trade in boiler and fire-box plates,

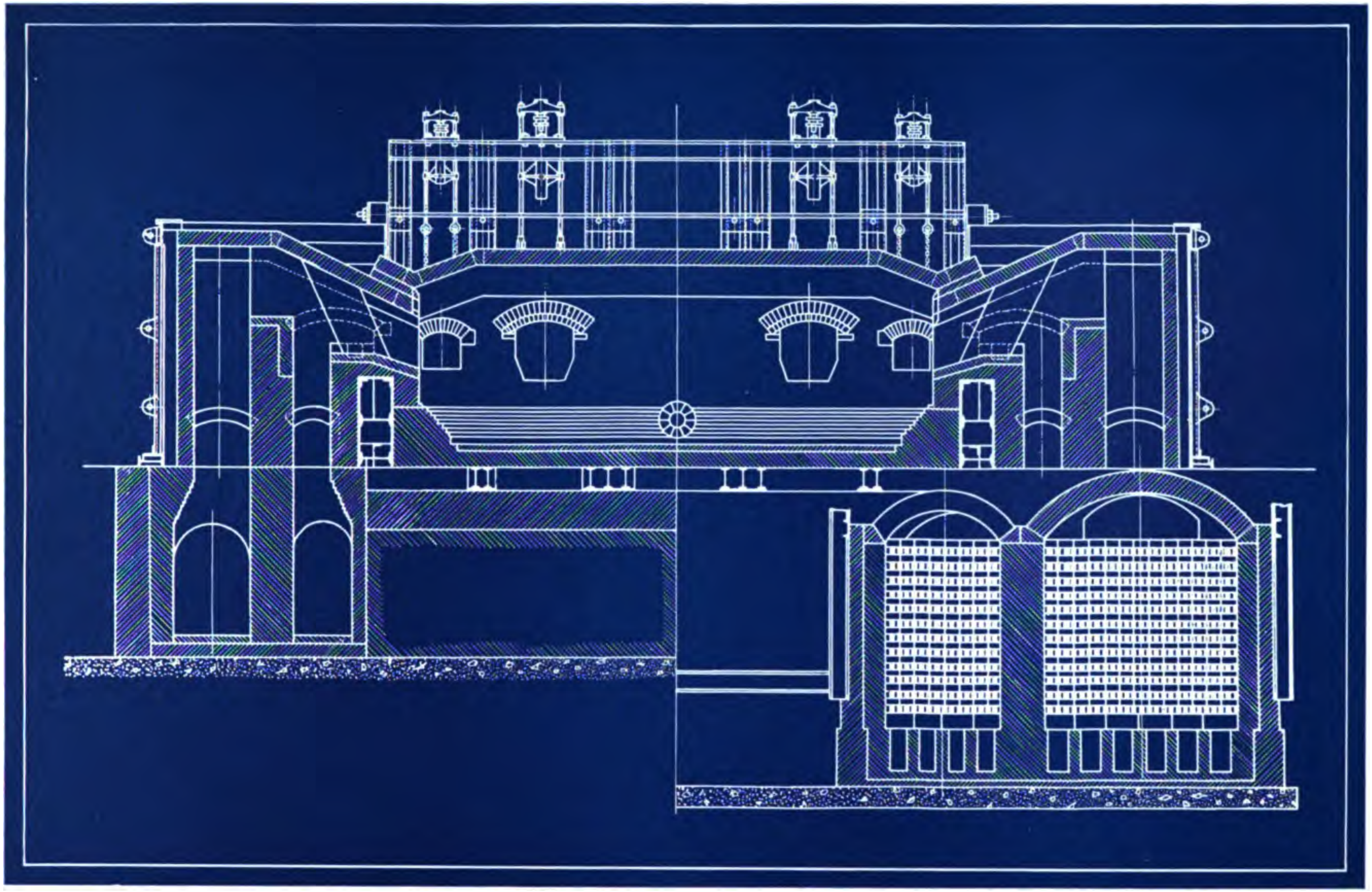


Figure 10—50-TON OPEN HEARTH FURNACE

This view shows the longitudinal section of a 50-Ton Open Hearth Furnace built for the Duquesne Steel Company, Duquesne, Pa., in 1900.

which they were able to hold for several years. Only one furnace was ever built at the Bay State Works, but this furnace was run day and night for several years in the manufacture of the highest class of ingots for boiler and fire-box plates, and as the price was very high, this small steel furnace earned a great deal of money for the company.

"The next firm to build an open hearth furnace was the Nashua Iron Company, Nashua, N. H. It was a 5-ton furnace, built under license from Messrs. Siemens. After I had finished and started the Bay State Company's plant, I was employed by the Nashua Company (of which my father, Mr. S. K. Wellman, had been for many years superintendent) to build and take charge of the new steel department at the Nashua works, consisting of the open hearth furnace plant, and a plate and bar mill. The building was started in 1871, and completed and put in operation the following year. There were some radical changes made in the plant from that of the Bay State Company; no preheating furnaces were used, blooms, when they were used, being heated in a pair of chambers on the charging side of the furnace, and pushed off into the bath when they had reached the proper temperature. English hematite pig iron was used for the bath, to which were added charcoal blooms from the Lake Champlain district, similar to those used by the Bay State Company when making the best quality of steel; a cheaper grade was made from steel and iron scrap, and pig iron. Ferro-manganese was melted in a regenerative crucible steel melting furnace from a mixture much the same as that used at the Bay State Works. The steel was tapped from the furnace into a ladle, mounted on a car running on rails, these being placed on each side of a deep casting pit, in which the ingot moulds were placed. The pit ran at right angles to the furnace, the ladle car being hauled by a chain and windlass worked by hand, thus making a cheap and effective casting arrangement. For a stationary furnace, it had a great advantage over the use of a shoe, similar to those used on the Bay State and Trenton furnaces, as no matter how cold the steel was, it was always hot enough so that it ran "clean" out of the furnace. While some of it might chill in the ladle, the furnace was not interfered with at all, and we were able to get out the next heat without interference from steel left in the furnace. Such a casting arrangement as that used at Nashua would not answer in these days of 50-ton furnaces, but it answered the purpose very well at that time. I have a vivid recollection of the first week's work after we started up the furnace at Nashua; we ran single turn, and were trying to make steel from cheap stock for some common forgings, but not an ingot in the whole week's work would forge at any temperature, and you may be sure I went home, that Saturday night, sick in mind and body. I do not remember the sermon on that Sunday; but before Monday morning I had found out the trouble with my steel making, and after the first heat on Monday morning, which proved to be all right in every respect, things looked brighter to me. From that time on, we had no serious trouble in making any steel we wanted.

"The Nashua Company were large manufacturers of forgings for railroads and marine uses, and much of the steel made by them was used to take the place of iron for this purpose. They also secured quite a large trade in boiler and fire-box plates, and later on commenced to manufacture steel for locomotive and car-wheel tires. Some years later this 5-ton furnace was torn down and a furnace of ten tons' capacity was built in its place.

"About the same time that the Nashua Company were building their first furnace, Messrs. Singer, Nimick & Co., of Pittsburgh,

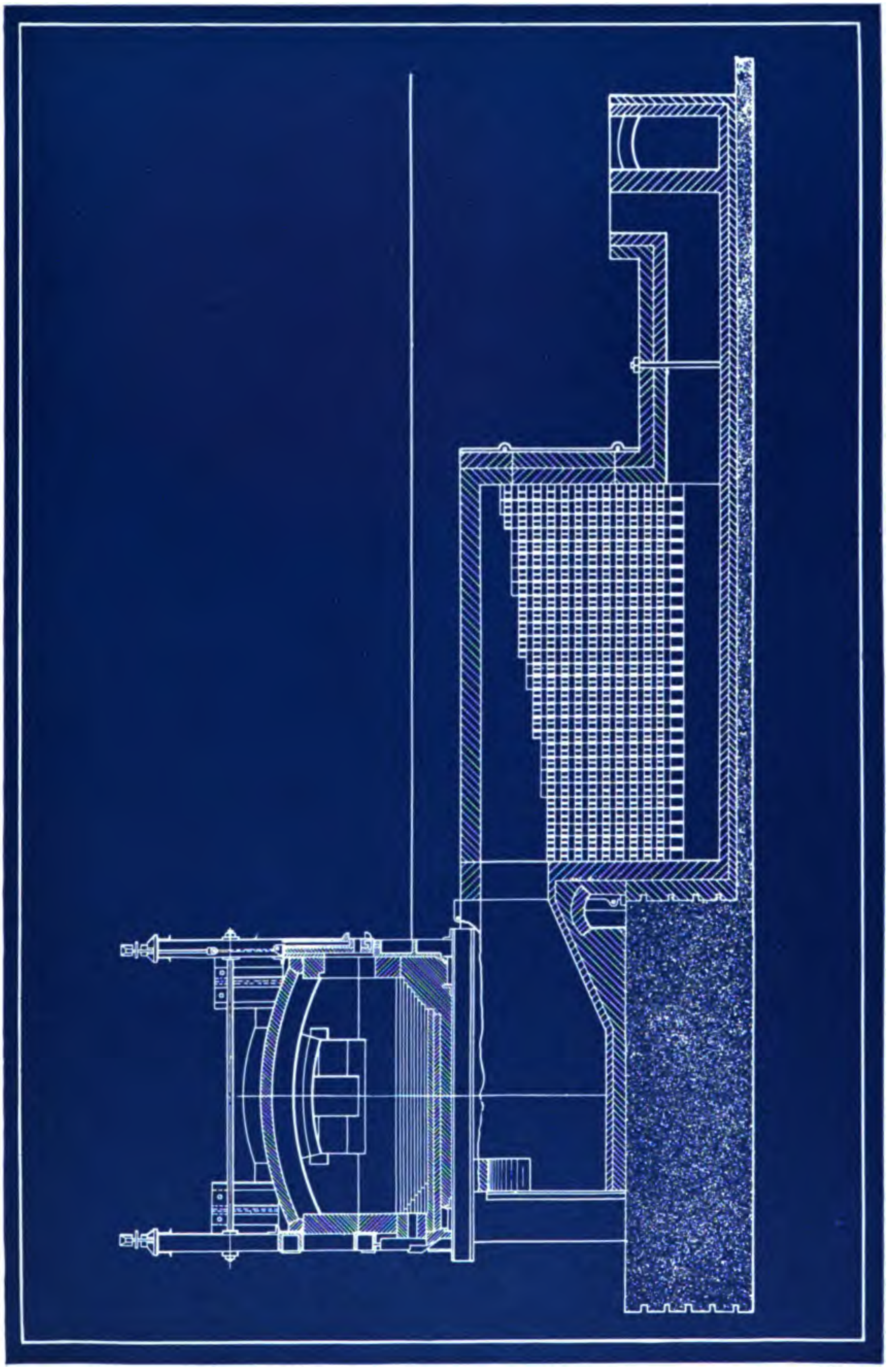


Figure 11—50-TON OPEN HEARTH FURNACE

This view shows the transverse section of a 50-Ton Open Hearth Furnace built for the Duquesne Steel Company, Duquesne, Pa., in 1900.

were building a furnace of nearly the same size, which was used for the manufacture of mild steel, principally boiler and fire-box plates, previously made from crucible steel.

"Following the starting of the open hearth furnace at Nashua, and that of Singer, Nimick & Co., there came the new works of the Otis Iron & Steel Company, of Cleveland, which was the first plant in the United States to be built for the exclusive manufacture of open hearth steel. I was engaged by the company to build and take charge of the works. A splendid location was found, almost in the heart of the city of Cleveland, near the shore of Lake Erie, with the Lake Shore & Michigan Southern Railroad on one side and the Pennsylvania Railroad on the other, giving ample railroad facilities, with competition both on incoming and outgoing freight. Ground was broken for the erection of the works in the summer of 1873, but they were not finished until the fall of 1874. At my suggestion, Mr. Alexander L. Holley was appointed consulting engineer, and served the company for several years in that capacity.

"I had seen Mr. Holley but once before he came to Cleveland on the occasion of his first visit as consulting engineer. That was seven years before, when he was in charge of the works at Troy, and I, wanting to learn the steel business, had asked him to give me a position there. He told me that he had no vacancies at that time. On his visit to Cleveland I recalled this circumstance to him, and laughingly said, 'As long as you would not give me a position, I have at last succeeded in getting you one.' This was the commencement of one of the most pleasant friendships of my life, which lasted until Mr. Holley's death.

"Many plans for the general arrangement of the works were considered between us, and the one finally adopted, with some minor alterations, was one suggested by him. The steel-melting plant, as originally built, consisted of two 7-ton furnaces (Fig. 7) with a regenerative, preliminary furnace for preheating the blooms, before adding them to the bath, and a regenerative-crucible, ferro-manganese furnace. The most radical improvement over old practice was the raising of the charging platform about 10 feet above the general level, the material to be melted being raised by hydraulic elevators, an arrangement which made the furnaces very accessible for repairs, and also gave the great advantage of being able to use a shallow casting pit. This plan is still followed by the latest and best works in this country.

"The steel was tapped into a ladle, as at Nashua; only, instead of supporting the ladle on a car, it was carried on the arms of a jib crane, which was simply a swing, without any lift. This made a simple and cheap casting arrangement, and one that was perfectly safe. The one crane stood on the center line between the two furnaces, and the ladle swung around to the tapping spout of each; as there was no lifting of the ladle when it was filled with metal, there could be no break-downs or upsetting. Since the ladle could not be lifted, we were obliged to bring the top of the moulds or groups to very nearly the same height, which in the case of moulds of different lengths was sometimes a disadvantage, but the safety of the whole arrangement more than compensated for this. A swinging platform for the workmen to stand on when tapping the furnace was supported at one end on the mast of the ladle crane, and at the other on wheels which ran on the plates covering the walls of the casting pit. The furnaces were very simple in construction, and much like the one at Nashua, excepting that the heating chambers on the front of the melting furnace had been dispensed with, and a preliminary furnace used, as at the Bay State works; one furnace with doors on each side served for the two melting furnaces. The first heat of steel was made in October, 1874, of charcoal

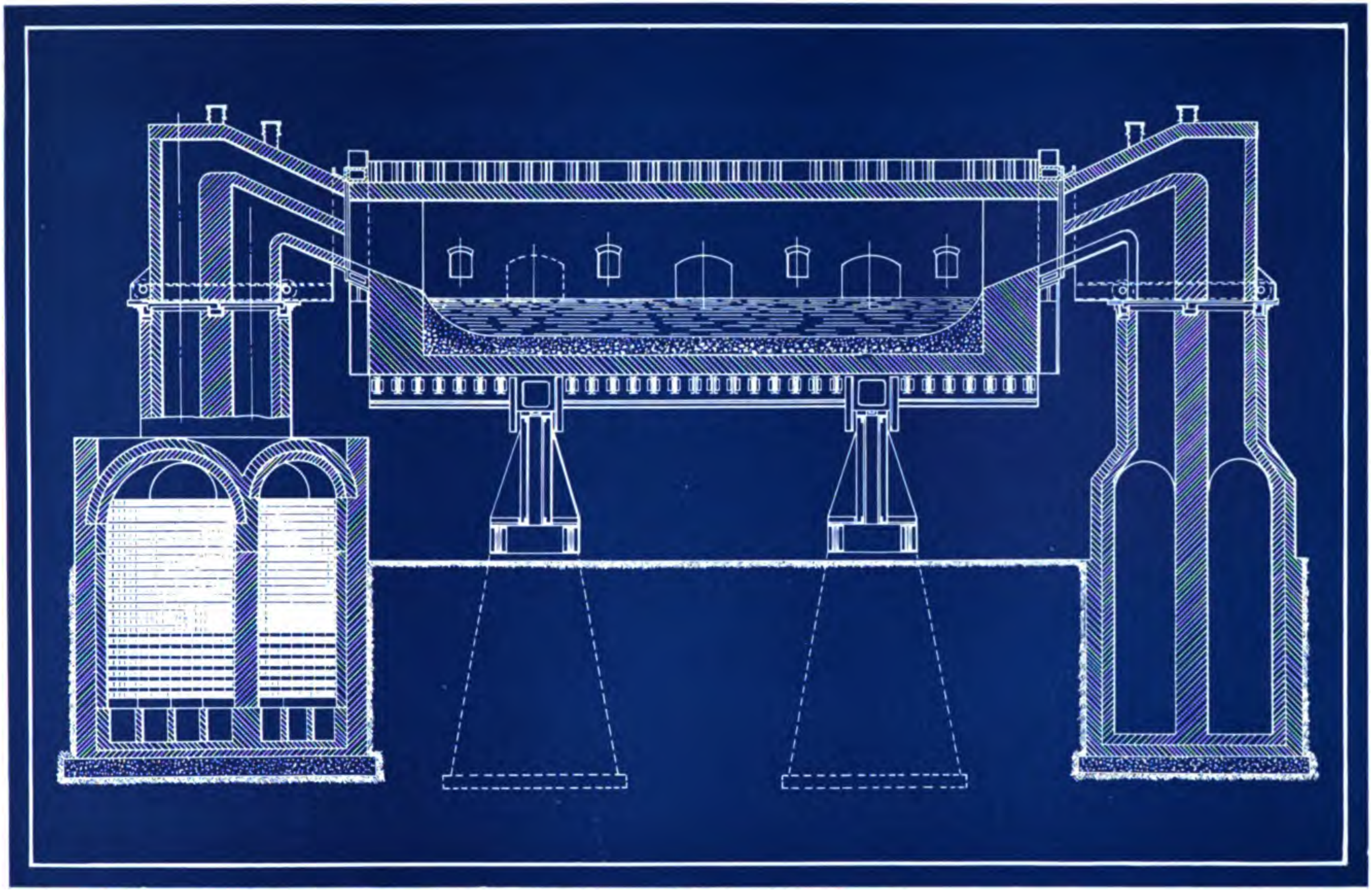


Figure 12—TWO HUNDRED-TON OPEN HEARTH FURNACE

Transverse Section. Proposed 1901.

blooms from the Lake Champlain district, melted in a bath of Lake Superior charcoal pig iron. The steel was naturally of very high quality, and was made into plates for fire boxes.

"The starting of the works was attended with the usual mishaps which always attend the launching of new enterprises, especially in the iron business. The first thing to happen before any metal had been charged into the furnaces, was a terrific gas explosion, which cracked the main gas flues, loosened up the gas and air valves, smashed man-hole plates and escape valves, and disarranged things generally. After our furnaces were started, they were occasionally fused down by careless melters, and the steel did not always prove to be what was expected; but a careful system of inspecting prevented these mistakes from getting to our customers, and after a few months' schooling of this kind things began to work smoothly, and we had comparatively little trouble in making what we wanted. Of course, we had to educate all of our skilled men; having no works from which to hire them, we had no other way. Our head melter, who originally came from New England during the construction of the works, was by trade a bricklayer—a bright and observing fellow, who was ambitious to learn the steel-melting business. I sent him to Nashua and Boston some two or three months before we started up the works, to learn what he could about the operation of the furnaces there. Of course, for a time he needed constant watching, but after a few months' work he became a very expert melter. Nearly all of our skilled men learned their trade after entering the employ of the Otis Company, and when I severed my connection with the company, after sixteen years' service, out of about 1,000 employees, I was able to learn of only one skilled workman who had not learned his trade in the shops of the company.

"Not only men, but all of our materials had to be tried and proven. The question of firebrick, as well as of other refractory materials, was an important and troublesome one and a great deal of experimenting had to be gone through before the best materials could be found. In the meantime we were building up a good reputation for the quality of our product, which was principally plates for boilers and fire boxes. 'OTIS STEEL' was for many years a standard brand for that purpose in this country, and sold at the very highest price.

"In 1878 two 15-ton furnaces were added to the plant. These were a great success from the very start, were regarded as of immense size, and were a radical step in advance of anything that had been built up to that time. In 1881 two more 15-ton furnaces were added, and in 1887 two more of the same size (Figs. 8 and 9). The last two were a distinct departure from anything that had been built before, in that the regenerators were under the charging platform instead of under the furnace proper. The opening into the regenerators was at the end next to the furnaces, instead of at the top, as is necessarily the case where the regenerators are underneath. This opening in the case of both gas and air regenerators was into a large slag pocket directly under the ports; since that time this type of melting furnace has been very largely used in this country, all of the late furnaces at the Homestead Steel Works, Duquesne Steel Works (Figs. 10 and 11), and the Sharon Steel Works being of almost exactly this type. The Otis Works was at one time the largest open hearth plant in this country.

"As I have said, the principal raw material used at the start for making the high quality of soft steel which was turned out at the Otis Works was charcoal blooms from the Lake Champlain district. These were used in largely increasing quantities from year to year, until the annual consumption reached

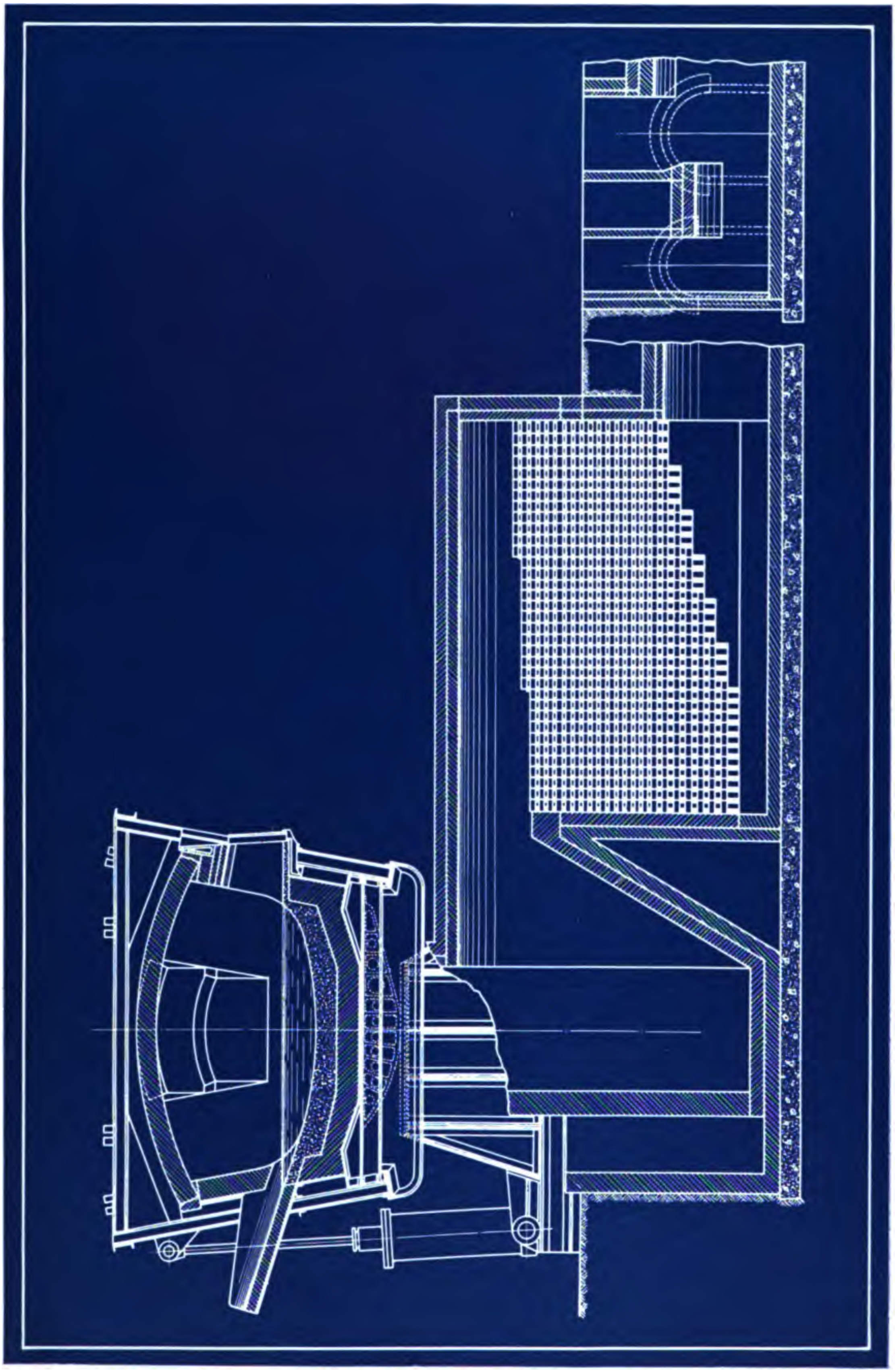


Figure 13—TWO HUNDRED-TON OPEN HEARTH FURNACE

Longitudinal Section. Proposed 1901.

as high as 12,000 to 15,000 tons, at an average cost of $45 to $60 per ton. This seems like an enormous price to pay for raw material; it was, but as the finished plates were sold at from $135 to $160 per ton, a fairly good margin was left for profit. Later on, a larger amount of puddled blooms were made from Bessemer pig iron in mechanical puddlers. Washed metal made in revolving Pernot furnaces by the Krupp-Bell process was also used.

"The first basic steel produced in this country was made at the Otis Works in 1886. During a visit to Europe in 1885 I saw the process at work and was much impressed with its possibilities. I immediately arranged to have a small cargo of Styrian magnesite sent over; and as soon as we could spare a furnace to make the experiment, we put in a lining of calcined magnesite on top of the silica bottom, which had been melted down as low as possible. This magnesite was not fused in, as is the practice in these days, but after being mixed with tar was rammed in place while the furnace was cold, following the practice in Europe at that time, which we had seen. As soon as the bottom was made, we started up the furnace, which was operated experimentally for some four months, making a good quality of basic steel. All of it went to our regular customers in our regular work, without any fault being found. It was kept as a great secret, and no one outside of the company's works knew what we were doing. During all of this time we were extremely busy. The basic process was much slower in operation than the acid, and this made the output of the furnace so small that I was at last forced to yield to the pressure brought by the selling department for more steel, and changed the furnace back to the acid process. Some months later the basic process was started at the Pennsylvania Company's works at Harrisburg and the Carnegie works at Homestead. Today at least three-fourths of all the open hearth steel made in America is manufactured by the basic process, and this proportion is bound to increase. The basic process of steel making is so simple, both in theory and practice, that it seems strange that it was not thought out and put in practice before it was. The same principles are involved, and the same reactions go on in the puddling process which has been in use for generations. The only difference is that the temperatures are lower in the puddling furnace than in the open hearth; as a consequence the lining in the latter must be the more refractory.

"Twenty-five years ago it was considered an axiom that phosphorus could not be removed from iron at a high temperature, but the invention of Snelus and Thomas demonstrated that it could be done. Today thousands of tons of steel are being made by the basic open hearth process from iron containing more than 50–100 of 1 per cent phosphorus, that is better in every respect than was the steel of which I have been telling you, made from costly charcoal blooms containing only 2–100 to 3–100 of 1 per cent of that element.

"Very soon after the Otis steel works were started open hearth furnaces began to be erected all over the country. They were built by the Pennsylvania Steel Company at Steelton, Pa., Cleveland Rolling Mill works at Newburg, near Cleveland; the Schoenberger works, at Pittsburgh; and many others, among all of which the Carnegie works at Homestead were the most important. This is today the largest open hearth plant in the world, consisting of 48 furnaces, of a capacity of from 40 to 50 tons each, having a total capacity of at least 1,300,000 tons per annum. The size has increased from the little 5-ton furnaces at Trenton and Boston up to those having a capacity of 50 tons, which is the average size now being built. Furnaces of this size nominally, at Ensley, Ala., have made heats yielding 74 gross tons of ingots.

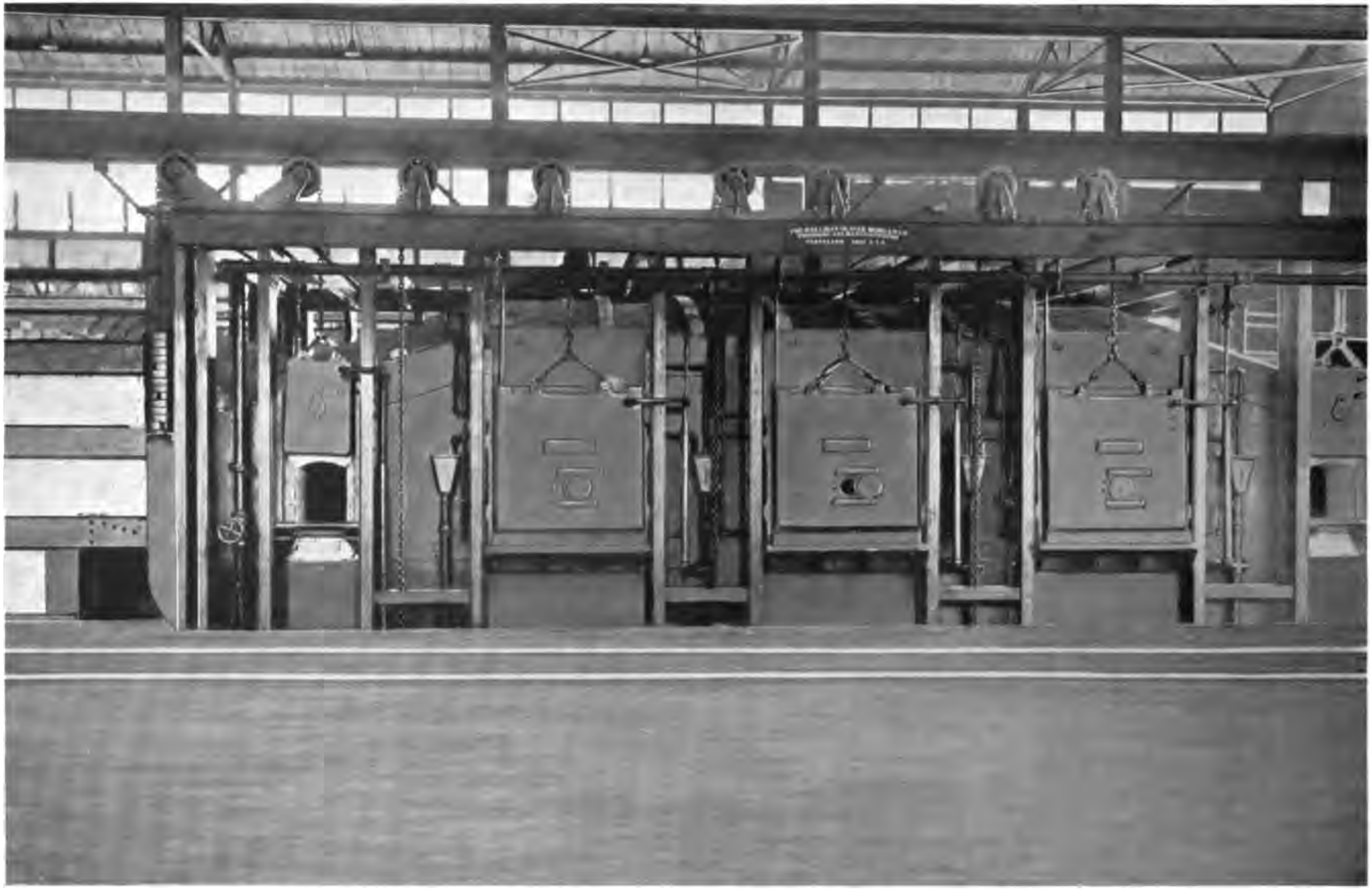


Figure 14—A 20-TON WELLMAN OPEN HEARTH FURNACE

Installed at the Marion Steam Shovel Company, Marion, Ohio, showing water cooled doors, joints, and arch plates. On a furnace of this size about 800 gallons of cooling water are required per hour.

"Furnaces of 100 tons' capacity are being built, and designs have lately been made for a furnace which will probably be built of 200 tons' capacity (Figs. 12 and 13). These large furnaces, however, are not properly melting furnaces, as the bulk of all the iron is charged into them in a liquid state, direct from the blast furnace. They might more properly be called 'converting furnaces.'

"The output of open hearth steel has grown from 893 tons in 1869 to 3,402,552 tons in 1900, against 6,684,770 tons made by the Bessemer process in 1900. But few new Bessemer converters have been built in this country for several years, and it is not likely that many more will be built. The production of basic open hearth steel in this country will soon exceed the Bessemer in tonnage. Mr. Holley used to say that 'the open hearth process will some day go to the funeral of the Bessemer.' It will be many years before that will come to pass, but the day is not far distant when the great bulk of all the steel in this country, at least, will be made on the open hearth of the Siemens regenerative furnace by the basic process.

"The drawings which I am able to place before you show the progress in the size of the furnaces, increasing from a 5-ton furnace at the Bay State works up to the 50-ton furnace at the Duquesne works, and the 200-ton furnace which it is proposed to build."

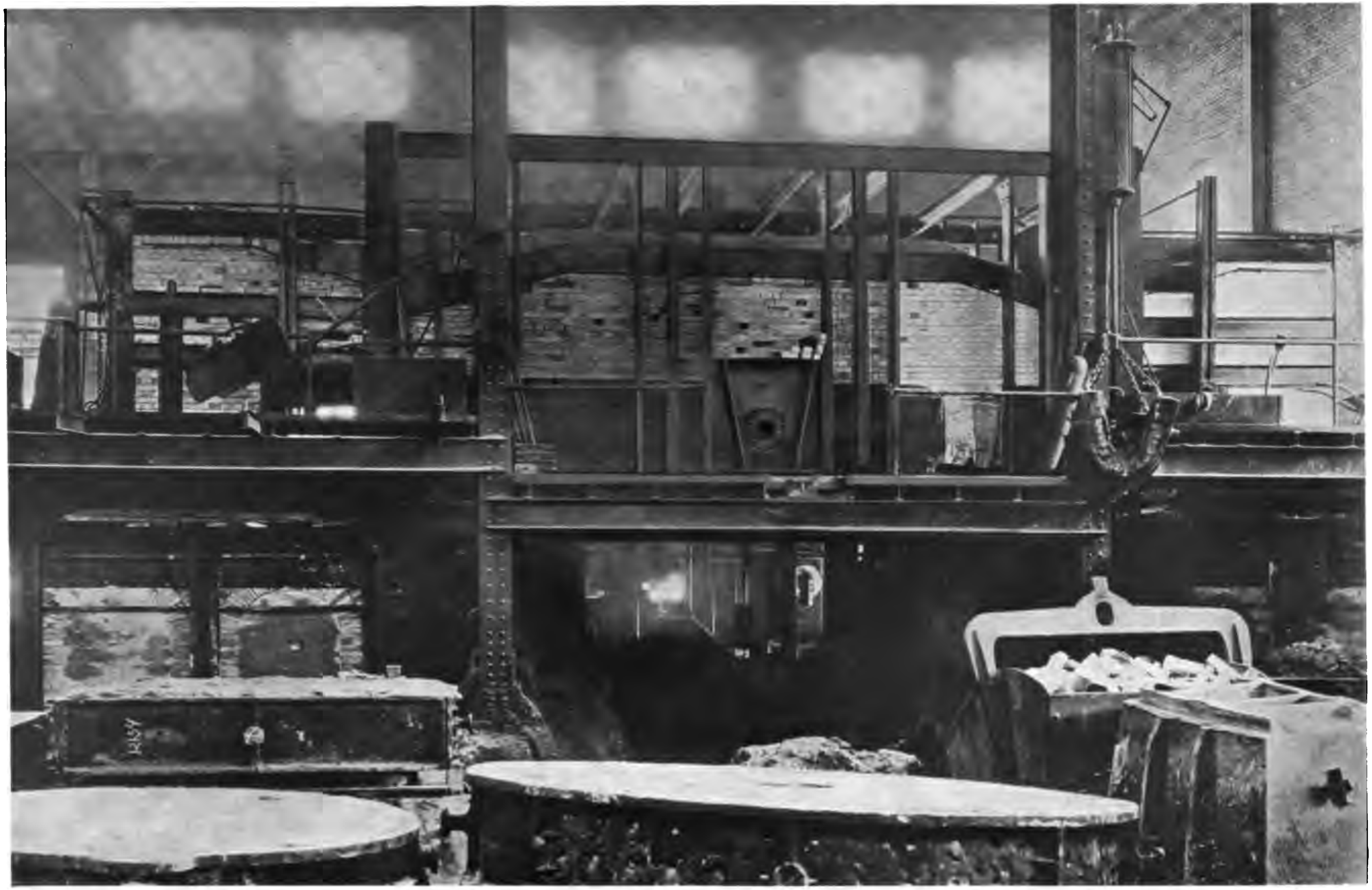


Figure 15—CASTING SIDE OF 20-TON WELLMAN FURNACE

Installed at the Marion Steam Shovel Company. The top cross ties of the furnace binding are riveted to steel channels. This gives a life of many years, holding the brickwork to its designed form, without distortion of the frame.

CHAPTER III

Processes Used in the Open Hearth Furnace

In this chapter the general characteristics of the principal open hearth processes are briefly described.

The Acid Open Hearth Steel Process

In the best design of an acid open hearth furnace, the bottom and hearth are built within a heavily reinforced steel pan. The lower two or three courses are preferably of silica brick though in some cases of clay fire brick. At the ends, the brickwork is stepped up toward the ports so as to have the sand bed of nearly uniform thickness. Where subject to scorification by the slag, the walls and port ends as well as the roof are built of silica brick.

Completing the Bottom

The furnace is gradually brought up to a melting heat and thin layers of silica sand are spread over the bottom. Sufficient time and heat is necessary to have each layer well sintered before putting in another layer of sand. The resulting hearth is of sixteen to twenty-four inches in thickness, and of an oblong dish shaped form. Before charging the first metal, the bottom is given, in some instances, a washing of a charge of open hearth slag.

A pure silica sand is not as satisfactory as a sand having a slight content of ferrous oxide (FeO) and alumina (Al_2O_3). These impurities cause the sand to "set" or partly fuse.

It is a common practice to mix these ingredients, rather than to trust to finding a natural sand of the required composition. The result is a bottom of long life resisting erosion by the molten metal. The character of the hearth lining fixes the kind of slag that can be carried in the furnace. This in turn determines the chemical reactions of the "heat."

Bessemer pig iron and basic or low phosphorus steel scrap in which the phosphorus and sulphur are both below 0.05 per cent are used. The iron is placed on top of the scrap so as to diminish oxidation of the iron in the scrap to prevent undue iron loss and eating away of the lining.

The slag formed is the product of oxidation of silicon, manganese and some iron of the metal charged, together with some silica from the hearth. The excess carbon of the charge is largely oxidized by the oxygen of the ore. When decarburization has been attained, the proper amount of manganese in the form of ferro-manganese is added as the steel is run into the ladle. The function of the "ferro" in addition to controlling the carbon percentage of the steel is also to remove the gases, oxygen, hydrogen and nitrogen from the bath. The success of the operation depends on maintaining a fluid slag (neither thick and pasty from too much silica, nor frothy from too much oxide of iron). The balance between the unfavorable conditions of excess of silica or iron oxide is maintained by controlling the furnace temperature with suitable additions of ore. The slag is largely self-regulating through additions to it of silica from the hearth to

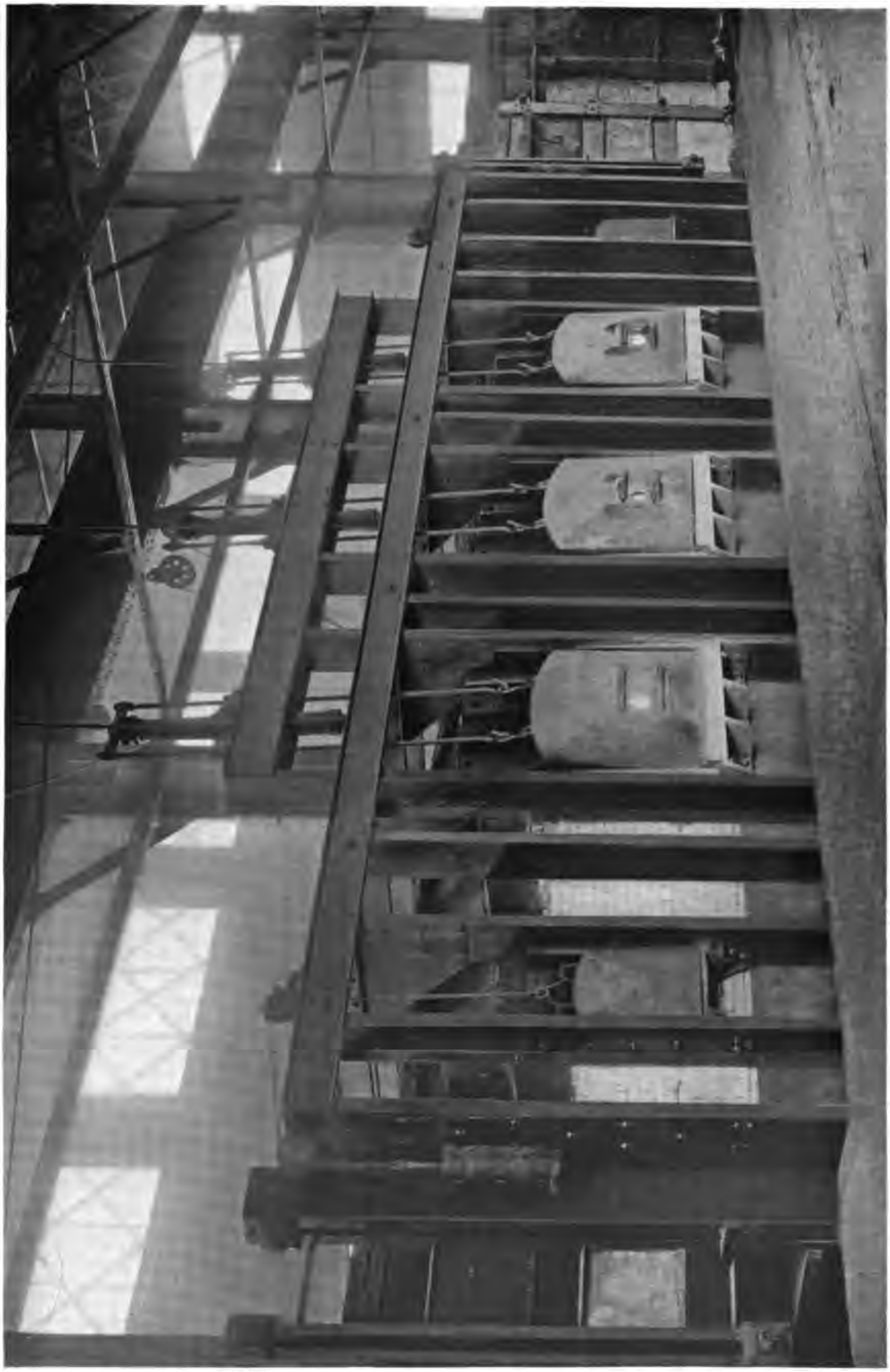


Figure 16—CHARGING SIDE OF A 35-TON WELLMAN FURNACE

The charging doors are operated by hydraulic power through lifting cylinders carried on a frame above the furnace binding. The small side doors being counterbalanced are easily opened and shut.

supply a deficiency in the charge, and by absorbing oxide of iron from the metal of the bath. Manganese is useful as a substitute for iron, which otherwise would be oxidized and pass into the slag. Prior to tapping the heat, the bath is brought to the correct temperature, the carbon content ascertained by inspection of test sample fractures, checked by chemical analyses. The trained judgment of the steel melter notes by visual inspection from the quietness of the steel and the temperature indications whether the metal is ready for tapping into the ladle. In heats of 20 tons and upwards with manganese below 0.65 per cent by adding ferro-manganese in the steel ladle perfect homogeneity of the steel is secured. With small heats, should the temperature not be suitable, better results are obtained by adding the ferro-manganese in the furnace. This requires a larger amount, due to rapid oxidation of the manganese from the oxygen of the slag and flame.

Other recarburizers are spiegeleisen, ferrosilicon, silico-spiegel, carbide of silicon, pig iron, coke, coal, or charcoal powder. Aluminum is an active deoxidizer, but it has a tendency to cause piping in the ingot, under certain conditions.

In studying the effect of steel, as affected by its metalloids, it is found that the coefficients used in the equations for the tensile strength of acid and basic steels are of different values. This points to a difference in the qualities of the two steels. The phosphorus contents being alike, less carbon is needed in acid than in basic steel to secure a metal of the same tensile strength. Experience shows that a "soft" or low carbon steel is preferable, generally, to a "hard" or high carbon steel, and that acid steel is superior to the basic metal.

The Basic Open Hearth Steel Furnace

The steel framework and pan holding the furnace is the same for a basic furnace as it is for an acid hearth.

The bottom brick are first quality clay fire brick for 2 or 3 courses. On these are placed three or more courses of magnesite brick. The sides and ends are likewise of magnesite brick.

"Dead burned" grain magnesite is spread over the bottom brickwork and fused in layers, building up the walls so as to form a dish shaped hearth, exactly the same as the sand bottom is built and sintered in an acid furnace. The magnesite is carried up, above the slag line. Above this, silica brick completes the construction. To hasten the setting of the bottom 5 to 15 per cent of basic slag is mixed in with the magnesite, before placing it in the furnace.

The construction is completed by pouring into the heated furnace a "wash" heat of basic slag or roll scale. This increases the density of the bottom. Such of the wash heat as has not soaked into the hearth is tapped off.

The magnesite brick are often topped off with chrome brick run two courses high.

Magnesite and chrome brick have a life sometimes 15 or 16 times that of silica brick.

The tap hole is made with magnesite brick or ground magnesite made plastic by being mixed with anhydrous tar. Chrome ore of the correct composition is the best material for the tapping hole.

The work of the basic furnace differs from that of the acid furnace in that it must remove as much phosphorus and sulphur from the metal as possible. To do this a flux of limestone is added to the charge. Phosphate of calcium is formed and becomes a stable part of the slag.

The Wellman Tilting Furnace

This furnace embodies sound mechanical principles as applied to furnace building, and in operation presents a number of important special features.

As the tapping hole is above the level of the bath when in the normal or melting position, it requires merely a loose closing stop-

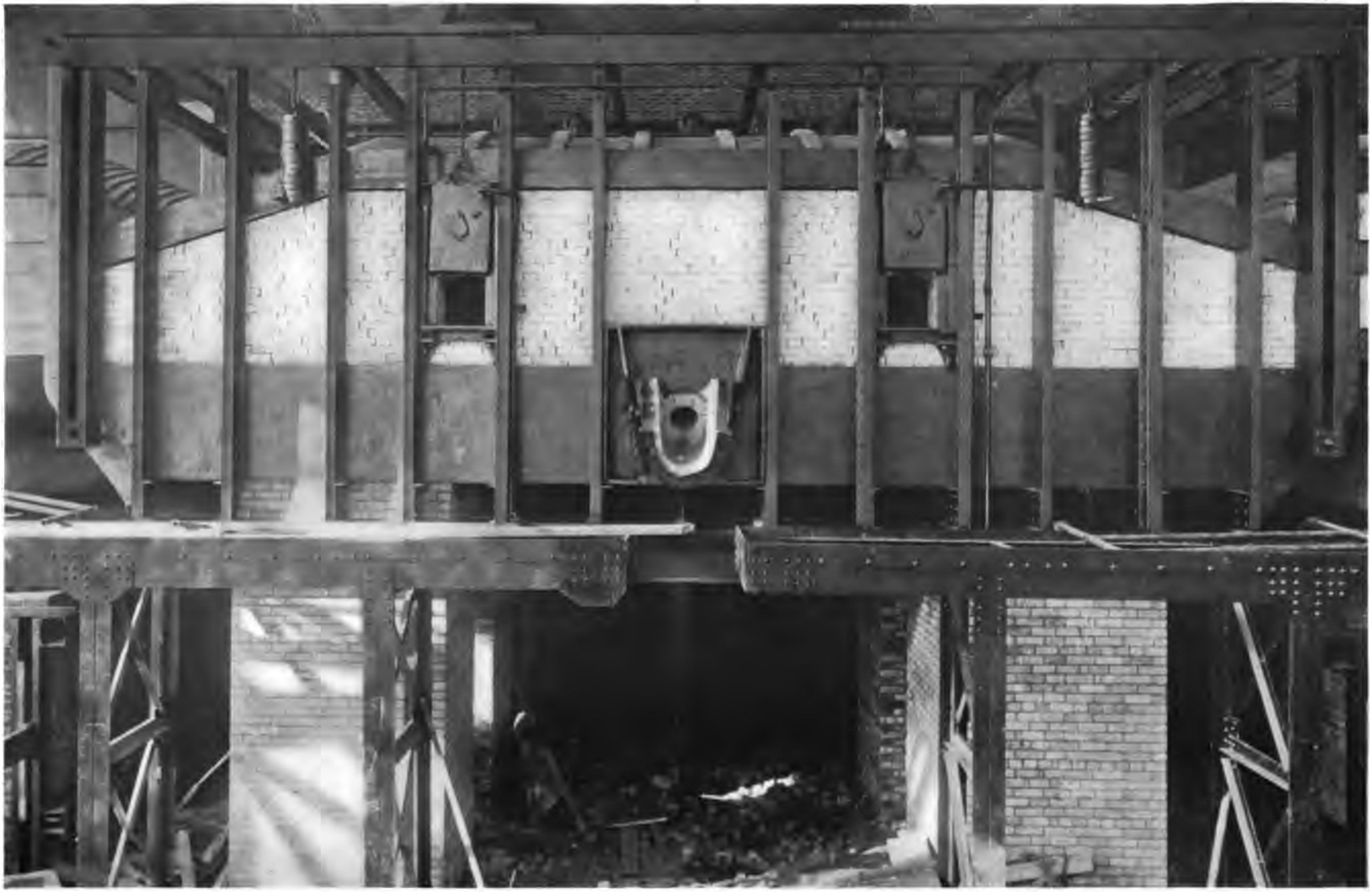


Figure 17—35-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

At the U. S. Arsenal, Watertown, Mass. The expansion in the silica brickwork is localized at each brick instead of accumulating at the ends, where special arrangements would be required to accommodate it.

per to exclude the air, thus doing away with drilling a hole for the steel to run out. This shortens the time between tapping and changing the next heat. The charge can be tapped at the exact time desired to secure the required composition of the metal. The slag can be poured whenever desired during the time of melting. Every particle of metal and slag can be removed after each charge. These features have resulted in a saving of 2 per cent of metal.

The transfer of metal at any period of the melting from an acid to a basic furnace or vice versa is readily accomplished when using a tilting furnace. On this feature is based the Talbot, Bertrand-Thiel and the duplex processes. In foundry work pouring of castings with hot steel can be done with certainty as ladles full of metal can be taken from the furnace one at a time.

Benjamin Talbot, in 1899, devised in Alabama, a modification of open hearth practice known by his name, which is founded on the powerful oxidizing action of slag rich in iron oxide. The operation is worked in a tilting furnace of large capacity running up to 250 tons each. The operation is continuous throughout the week's run, after which the furnace is drained for patching. The main metallurgical feature is the use of pig iron and oxides of iron such as mill cinder, roll scale, or iron ore, without necessarily using scrap steel. A fractional part as a quarter to a half of the metal is tapped at a time and the original quantity restored by additions of metal, oxides and limestone.

The reactions are violent and rapid, due to the richness of the slag in oxides of iron, and refining proceeds at a high speed. The discharge and combustion of the large amount of carbon monoxide formed produce a vigorous boiling similar to that found in a Bessemer converter. The generation of heat is so great that the fuel gas fed to the furnace is shut off for a while. In a short time the iron oxide in the slag is so reduced that a part of the slag is poured off.

Decarburization of the iron into steel is effected by addition of iron ore and limestone. The furnace is then tapped. Additions to the charge are made and the process continues. A heat is completed in less than five hours.

Probably the tilting furnace is indipensable to the duplex, the triplex and other similar processes. The operation of refining is carried on more satisfactorily than in the stationary furnace. It is susceptible of greater tonnage of output than the stationary type, furnace for furnace. Its advantages over the stationary furnace are many. Among them are the following:

1. A greater tonnage of output.
2. Easier to drain completely of slag and metal.
3. Easier to repair the lining.
4. Refining carried on more satisfactorily.
5. Slag pit can be kept cleaner, and due to the control possible with the tilting furnace slag may be poured from the tapping spout, prior to tapping the metal.
6. Pouring of metal and slag are under perfect control.

In a plant equipped with five 180-ton tilting furnaces from which 50-ton heats are poured, the monthly production averaged 8,000 tons per furnace.

The process is valuable for its continuous operation and consequently very large onnage of output. A basic furnace is especially useful in operating with high phosphorus raw materials or metals of irregular silicon compositions. When a sufficiently high phosphorus pig iron is used, the basic slag is so rich in phosphates as to be saleable as a fertilizer.

By not drawing off at one time more than a third of the metal, the fluxing action of the slag is confined to a zone of the lining a few inches wide above the metal, and the bottom of the hearth is protected from slag scorifi-

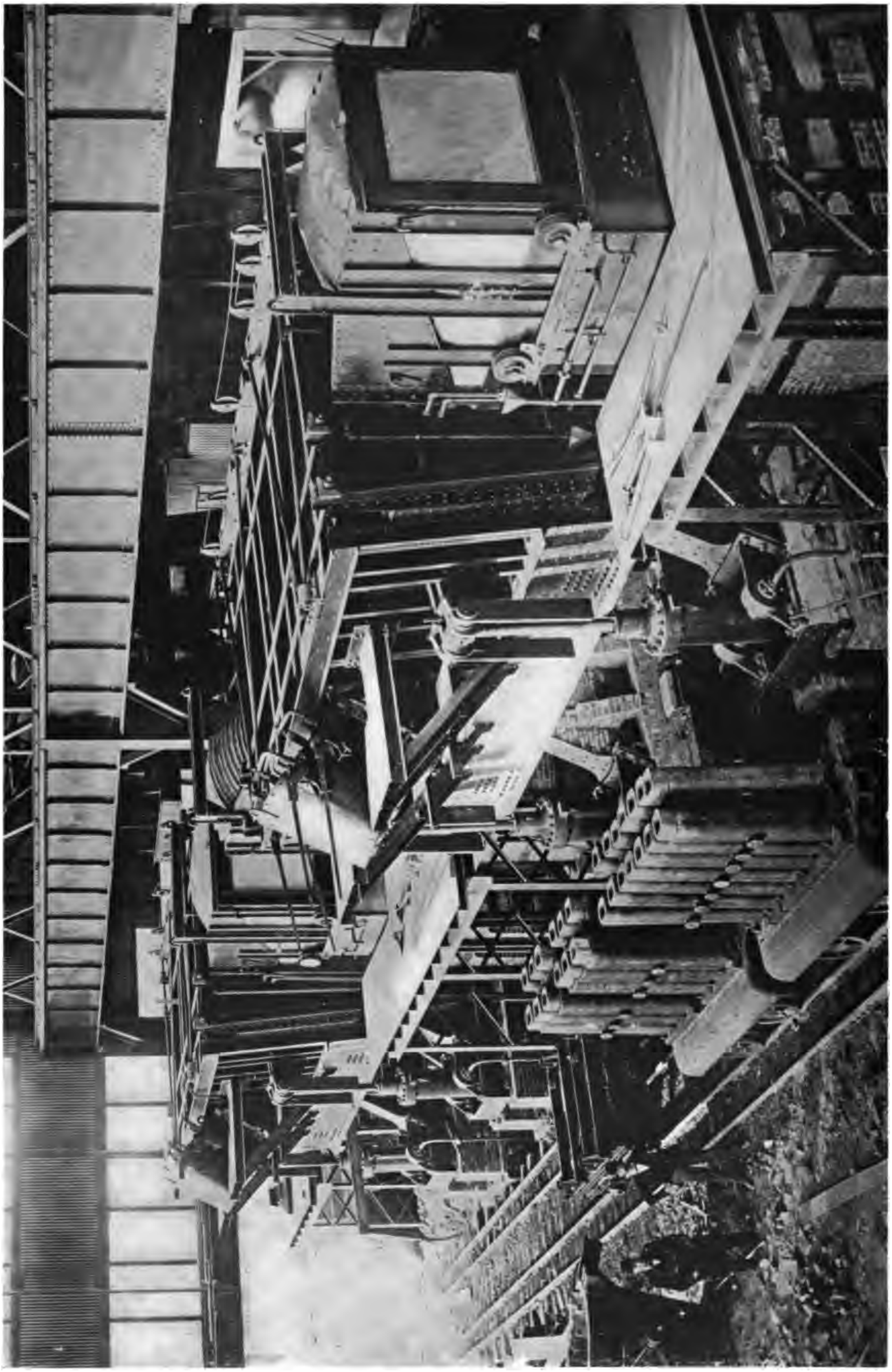


Figure 18—TWO 50-TON HYDRAULIC OPERATED TILTING WELLMAN FURNACES

These furnaces cast direct into the molds, standing on cars, without the interposition of steel ladles using a fore hearth. From one to four ingots may be poured simultaneously. "Hot tops" are used on the molds to overcome piping in the ingot.

cation except when the furnace is emptied at the end of the week.

The Talbot furnace is now used as an auxiliary in the Triplex process in which steel is finished in the electric furnace.

It is the type most adaptable to the working up of pig iron of varying composition, and to changes within fairly wide limits in the amount of scrap added.

In this furnace pig iron of the lowest to the highest phosphorus content can be worked up without deteriorating the quality of the steel, the decline in output with pig iron rich in phosphorus being smaller than in the case of other types of furnace.

Although the actual first cost of the furnace is appreciably higher than that of a tilting furnace of small capacity, or a fixed open hearth furnace, these costs, calculated on the daily tonnage produced, work out most favorably for the Talbot furnace.

The yield of metallic iron from the oxide additions (ore and cinder) is higher in the Talbot furnace than in other types.

The slag produced in the furnace is (owing to the concentration of the phosphoric acid when using pig iron high in phosphorus) more valuable than in the other types of furnace; and therefore the profits arising from the sale of the slag are greater.

The fuel consumption is lower in the Talbot furnace than in other furnaces.

The life of the refractory lining is longer than in other systems, and thus both the charges for repairs and the total consumption of refractory material are lowest.

The working in the case of the Talbot furnace is most simple and convenient, especially on account of the easy removal of the slag by tipping the furnace.

The work of the furnace staff is less trying than with other types; and the number of hands necessary for carrying out the process is relatively the smallest.

This is substantially the Talbot process as to the metallurgical reactions, and is carried on in a basic furnace, but of a stationary type. The entire heat is tapped at one operation. The flux of limestone and iron oxides are charged first. The pig iron is added when the oxides are almost reduced. As the highly corrosive slag is in contact with the hearth on tapping each heat, the bottom patching must be carefully attended to.

A mathematical analysis of the thermochemical operations of the reaction between the pig iron and ore shows that this is a heat generating operation. The evolution of the heat is sufficient to raise the temperature of the bath between 220° and 270° F. and points to a reduction in the consumption of fuel gas at that time.

The Surzycki Tilting Furnace Process

The Surzycki tilting furnace process is substantially like the Talbot.

The Campbell Tilting Furnace

This is a type of furnace developed by Campbell at Steelton, Pa., and differs from the Wellman furnace in tilting by revolving on its longitudinal axis, instead of tilting by rolling forward into a pouring position.

The Bertrand-Thiel Process

At Kladno, Moravia, the Bertrand-Thiel process of working phosphoric pig iron was inaugurated in 1894. This method involves the use of two open hearth furnaces on different levels. In the higher furnace most of the oxidation of the metalloids is accomplished, while the work is completed in the lower furnace. Transfer from furnace to furnace is made by means of a runner between them. An advantage of this process is that using a slag rich in oxides of iron the oxidation is rapid. The removal of the metal from the first slag which is rich in phosphorus prevents any tendency of a rephosphorization of the iron, by a recombination of a part of the phosphorus in the slag.

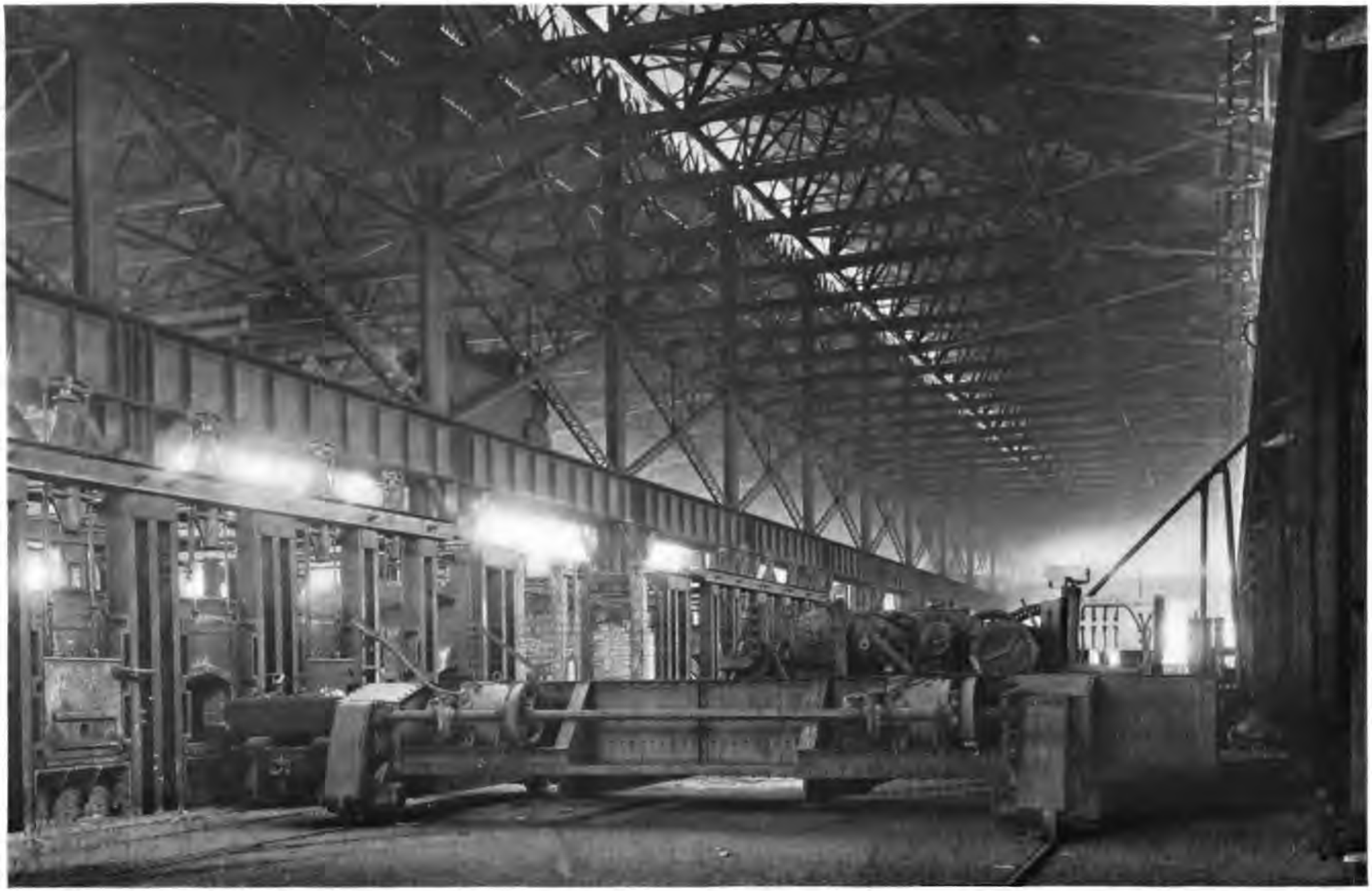


Figure 19—A BATTERY OF LARGE OPEN HEARTH FURNACES

This view taken at one of the Illinois Steel Company's plant shows a large battery of furnaces served by a low type charging machine.

The Lash Process

The advantage claimed for the Lash process in the open hearth is due to the relative cheapness of iron in the form of ore rather than as pig iron, so that the more ore is used the cheaper the product. The charge used in this process is finely divided ore, coke and iron high in metalloids. These metalloids including carbide of iron (Fe_3C) act as reducing agents. To the main items of the charge sawdust for porosity and a suitable binder are added when it is desired to use the charge in the form of briquetts. This is a process used preliminary to electric furnace refining. Published analyses of the final product show sulphur ranging from 0.02 to 0.13 and phosphorus from 0.015 to 0.038.

The Duplex Process

The Duplex process is the combination of desiliconizing and partially decarburizing the hot metal in a Bessemer converter and completing the refining in either an acid or basic open hearth furnace. It is best suited for pig iron high in silicon.

A good example of a duplex installation is one in which four 12-ton acid Bessemer converters are fed by twelve cupolas of which eight melt iron and four smaller ones spiegel when making high carbon steel. The Bessemerized metal is taken by two large tilting open hearth furnaces. These furnaces have a hearth 13 ft. 0 in. wide by 40 ft. 0 in. long. There are seven doors on the charging side.

Mixer cupola pig metal heats of 28,200 lbs. are charged into the converters of the following average analysis:

Total carbon	3.70%
Silicon	1.50%
Manganese	.65%
Phosphorus	.36%
Sulphur	.045%

Two Bessemer heats from different converters are poured into one open hearth furnace. The first ladle carries 0.40% carbon, then follows two of metal from 0.005% to 0.07% carbon. A fourth ladle of 1.5% to 2.0% carbon completes the charge on starting up at the beginning of the week's run. The last ladle full causes a vigorous reaction, during which dephosphorization takes place. When this is done, two more ladles of soft steel and one of high carbon steel are charged. If the bath is low in carbon, another ladle high in carbon is added and vice versa if high in carbon. In this way an open hearth charge or bath of about 200 tons is accumulated. The process then proceeds as in ordinary basic working. Eighty per cent of the steel thus made is recarburized in the ladle with molten spiegeleisen. The rest is made with ferro silicon, ferro-manganese, etc.

The resulting steel is tapped into a 100-ton ladle.

When sufficient steel is tapped to well cover the ladle bottom, the liquid spiegel is poured in. For rail steel, the weight of spiegel per heat runs from 25,000 to 28,000 lbs. The week's run starts Sunday 6 P. M. when gas is turned on and preparation of slag starts with charging 2,000 lbs. lime and 3,000 lbs. roll scale. The first ladle of Bessemerized metal is charged into the open hearth at 12:45 Monday morning. The week's run is completed by draining the furnace on Saturday at midnight.

In the operation of two open hearth furnaces in the time from May, 1913, to August, 1916, inclusive, the performance was as follows:

Total tonnage of steel produced	830,230 gross tons
Number of open hearth furnaces	2
Number of heats	8073
Time per heat	2 hr. 53 min.
Tonnage per heat	102.7 gross tons
Tonnage per month (best) 2 furnaces	50,071 gross tons
Tonnage per month (best) 1 furnace	30,272 gross tons
Tonnage per turn per furnace	427.6 gross tons
Heats per turn per furnace	4.14

Life of roof	499 to 1300 heats
Life of ports and slag pockets	3560 heats
Life of checkers	1718 to 4233 heats
Time in repairing brickwork	14½ to 23 turns

The Triplex Process

The triplex process as operated at South Chicago consists in blowing the steel in the Bessemer converter, refining it in the open hearth furnace and finishing in the electric furnace. The equipment consists of two 25-ton acid lined converters, three 250-ton tilting open hearth furnaces, two 15-ton and three 25-ton electric furnaces. The monthly capacities are 75,000 tons of Bessemer steel, 65,000 to 70,000 tons of open hearth metal and 16,000 to 17,000 tons of electric steel.

The electric furnaces forming a part of a triplex plant, are ordinarily operated with a reducing slag only. A thorough and complete deoxidation is sought for. After the steel is dead melted and chemical reactions are complete, as shown by careful slag and metal tests, then with a reduced current the proper pouring temperature is secured. On account of its freedom from gases, electric steel is very dense.

Steel making is not an exact science. It is an art in which science plays a large part. There is much yet to be learned in as much as the appraisal of the quality and usefulness of steel is a matter of experience quite as much as a matter of laboratory determination. Even though laboratory microscopical and physical analyses and tests show that under some conditions Bessemer steel is of as high quality as open hearth steel and that the latter equals electric steel, yet the final judgment is that of experience in the working and using of steel.

CHAPTER IV

Advantages of the Open Hearth Furnace

The Bessemer process requires a supply of pig iron containing much lower sulphur and phosphorus than is demanded by the open hearth process. In the latter process, the conditions imposed on the blast furnace are not so rigorous, as the open hearth is capable of desulphurizing and dephosphorizing the metal of the charge. Thus, the blast furnace is able to work more economically in producing basic open hearth iron than Bessemer iron. Its principal metallurgical task is to produce a large iron output, in which the silicon is under control, although with a considerable range in amount.

Bessemer steel contains oxide of iron, causing cracks; the sulphur content tends to cause the steel to roll red short, and the occluded gases form pipes and blow holes. On account of the violent boiling of the metal, minute particles of slag are mixed in the body of the steel. Unexpected flaws in the finished product continually occur and failure in laboratory tests and under actual working conditions are frequent. Open hearth steel does not suffer from these disadvantages to so great an extent, nor is the iron loss as great as in the converter.

The character of steel depends largely on the quality of the raw materials used. By the open hearth process, relatively cheap materials are convertible into perfectly usable steel.

A skilled furnace man, with a slightly increased time of melting, accompanied by a moderate addition of cost, can make an open hearth steel comparable in quality with crucible or electric furnace steel.

An acid furnace can do but little refining, other than desiliconizing and decarburizing, therefore a relatively high grade scrap, low in phosphorus and sulphur is needed.

The basic furnace on account of its basic slag uses a low silicon stock, and can dephosphorize as well as decarburize the material charged.

The economic justification, or argument, for the open hearth process is due mainly to the decreasing amount of available iron, low enough in phosphorus for the acid Bessemer or high enough for the basic Bessemer process. In the acid open hearth, the low phosphorus metal may be made into steel, while the basic open hearth similarly converts the high phosphorus metal. Good steel may be made of an iron running as high as 3% phosphorus. In the basic furnace, it is possible to secure an elimination of 75% of the sulphur and 95% of the phosphorus. Obtaining steel with sulphur as low as 0.030% and phosphorus of 0.020% is common practice in present open hearth working.

Owing to the nature of the process, the chemical composition and quality is always susceptible of ascertainment and control of the melter, while it is possible to alter its composition. There is less danger of over oxidation, less occluded gas and slag in the steel, a greater uniformity and reliability of product than in the Bessemer process. The yield of sound castings is also higher for the open hearth.

The open hearth is at a decided advantage in making steel castings, as a "dead" melted steel is often required in large quantities. It is essential also to produce a clean non-oxidizing slag. Lastly, the temperature of the metal must be under perfect control. Smaller castings require hotter metal than larger ones. All of these conditions are satisfied daily in acid or basic open hearth operation.

Formerly the highest grades of steel for cutlery, fine instruments, springs and dies were made by the crucible process. It is possible to produce open hearth steel of any desired carbon from 0.05 to 1.5 per cent, with phosphorus and sulphur each below 0.04 per cent and manganese below one-half of one per cent, and of a high degree of uniformity. On the other hand some Swedish crucible steels branded as 0.50 carbon have varied from .46 to .61 per cent. This is a variation of .15 per cent while the average variation between the carbon of the top and bottom of an open hearth ingot has been found to be as low as .07 per cent.

The Wellman open hearth furnaces are giving most satisfactory results in making "high speed" tool steels. They are used in government arsenals of this and other countries for the production of high quality steel forgings for guns and projectiles. Formerly this was exclusively the province of crucible steel.

The cost per unit of weight of electric steel is so much greater than for open hearth steel that it is used in a restricted field. Careful selection of stock and refining in an open hearth will produce steel of so excellent a quality as to meet the requirements imposed on electric steel. Assuming for both types of furnace similar raw materials, and quantity of output, the relative cost of the product will be determined by the cost per unit of weight for the plant or installation, the lining, electrodes and fuel.

The advantage of the open hearth over the crucible process is in quantity production. The crucible process produces steel in hundred pound lots at great expense for labor and for carefully selected high grade raw materials.Using materials for the charge of the same quality as for crucible work, a small acid open hearth furnace would turn out steel of equal quality and at a very much lower cost.

CHAPTER V

Operation and Performance of the Open Hearth Steel Furnace

Open hearth furnaces are built with capacities from two tons up to three hundred tons. The larger sizes are of the tilting type such as Talbot furnaces. A quite common size of furnace runs from 35 to 75 tons capacity, producing from 30 to 70 tons of ingots per heat in an eight hour melt.

Foundry open hearth furnaces commonly run from 15 to 25 tons capacity. Electric furnaces range from one to 25 tons per heat, and melt a heat in from one to two hours.

The enormous demand for the very high grade quality of steel for machinery, tools, ship plates, high powered guns and ammunition needed to keep in the field the armies of our Allies and ourselves, during the World War, could not have been met except for open hearth furnaces.

Bessemer steel could not measure up to the quality required. The crucible process was hopelessly inadequate as to capacity.

The severity of our Government specifications, accompanied by the rigor of its inspection, has been met by the open hearth and largely in the acid furnace, in a way that is as remarkable as it is creditable to American steel men.

Table No. 21 illustrates that acid open hearth steel costs $32.73 per ton, and basic steel costs $43.48 per ton in the ladle. The difference is due to the need of using pig iron in the basic process. The acid process has a busy future for many years to come, in that it uses the cheaper material, namely, steel scrap. As the steel industry continues, the supply of steel scrap is bound to increase.

The tonnage of unused munition steel in the country is very great at the present time, in addition to which there is a great deal of war material and machinery which will need to be remelted for commercial uses.

In designing the details of a plant or improving the technique of operation, a discussion of the efficiency of the various units in question is instructive. But the decisive figure is that of lowest total cost per ton of steel produced. This figure is given in Table No. 21. The economy of the open hearth process is there shown to be greater than that of any other steel making method. Especially is this the case for acid open hearth steel.

Basic operation results in a melt of steel relatively overcharged with oxygen, hydrogen and nitrogen. The degasification is accomplished in the ladle. No one deoxidizer will completely degasify steel—carbon in the shape of coal dust will not do so, regardless of quantity. Ferro-manganese added either in the furnace or in the ladle, produces oxide of manganese and this becomes a part of the slag. A portion combining with sulphur in the steel forms sulphide of manganese, which does not readily separate itself from the steel. This sulphide of manganese being present in all basic steel, at times is present in such amount as to produce seams in rolled steel and cracks in cast-

Table No. 6

Charge Sheet of a Basic Open Hearth Furnace

Materials Charged and Product	Per Ton of Ingots	Weights per Heat of (in Pounds)							
	Pounds	10 Tons	20 Tons	40 Tons	50 Tons	60 Tons	75 Tons	80 Tons	90 Tons
Hot Metal	1120.4	11200	22400	44800	56020	67224	84030	89632	100800
Cold Pig Iron	96.3	962	1924	3848	4815	5778	7222	7704	8658
Bloom Crops	590.3	5900	11800	23600	29515	35418	44273	47224	53100
Plate Scrap	19.5	195	390	780	975	1170	1463	1560	1755
Ingot Butts	59.1	590	1180	2360	2955	3546	4432	4728	5310
Rail Scrap	39.3	390	780	1560	1965	2358	2947	3144	3510
Tin Plate Scrap	26.6	266	532	1064	1330	1596	1995	2128	2394
Turnings	3.4	34	68	136	170	204	255	272	306
Steel Rod Scrap	103.9	1039	2078	4156	5195	6234	7793	8312	9351
Stirring Rods	2.8	28	56	112	140	168	210	224	352
Total Metal	2061.6	20616	41232	82464	103080	123696	154620	164928	185544
Fine Ore	200.0	2000	4000	8000	10000	12000	15000	16000	18000
Cinder	5.6	56	112	224	280	336	420	448	504
Roll Scale	5.5	55	110	220	275	330	413	440	495
Dolomite	68.0	680	1360	2720	3400	4080	5100	5440	6120
Limestone	153.8	1536	3072	6144	7680	9228	11535	12288	13824
Lump Ore	61.9	620	1238	2476	3095	3714	4643	4952	5571
Fluor Spar	2.7	27	54	108	135	165	202	216	243
Total Auxiliaries	497.5	4975	9950	19900	24875	29853	37313	39800	44775
Run of Slag	67.5	675	1350	2700	3375	4050	5063	5400	6075
Normal Slag	161.1	1611	3222	6444	8055	9666	12082	12888	14499
Total Slag (Furnace)	228.6	2288	4572	9144	11430	13716	17145	18288	20574
Additions									
Hot Metal	164.7	1647	3294	6588	8235	9882	12083	13176	14623
Ferro-Manganese	8.6	86	172	344	430	516	645	688	774
Ferro Silicon	0.6	6	12	24	30	39	45	52	54
Sulphur	0.3	3	6	12	15	18	22	24	27
Coal, Etc	2.1	21	42	84	105	128	158	170	189
Aluminum	0.2	2	4	8	10	12	15	16	18
Total Additions	176.5	1765	3530	7060	80	10590	13238	14120	15685
Total Steel Made	2240 lbs. – 1T	10 Tons	20 Tons	40 Tons	50 Tons	60 Tons	75 Tons	80 Tons	90 Tons
Ladle Slag Made	88.4	884	1768	3536	4420	5304	6630	7072	7956
Total Slag Made	317.0	3170	6340	12680	15850	19020		25360	28530
Fuel: Producer Gas Used	2599.	25990	51980	103960	129950	155940	194924	207920	233910
Air Used	7484.	74840	149680	299360	374200	449040	561300	598720	663560
Flue Gas Made	10582.	105820	211640	423280	529100	634920	793650	846560	952380

ings. Silicon acts in a like manner. Aluminum forms alumina (Al_2O_3) which clears itself from the metal rapidly. Even in steel high in manganese, carbonic oxide (CO) and oxide of iron (FeO) are present. The basic process must be resorted to where dephosphorization is necessary.

The influence of phosphorus in soft acid and basic steels has been studied recently from the standpoint of the behavior of such steels during fabrication and use in articles of ordinary commerce, such as rivets, cold drawn shafting, wire, threaded bolts, stamped work and automobile parts. The conclusions are that with a low carbon content phosphorus does not produce brittleness. An increase of 0.01% of phosphorus increased the tensile strength 850 pounds per square inch, practically the same as carbon. As phosphorus is increased, carbon must decrease to prevent hardness but tool steel of say 0.7 to 1.0% carbon becomes brittle if the phosphorus exceeds 0.03 to 0.4%.

The time of a basic heat is somewhat prolonged, approximately 1½ to 2%, on account of the absorption of heat in reducing the limestone ($CaCo_3$) of the flux to lime (CaO). There is an advantage, however, in that the gas bubbling through the bath keeps up a motion which facilitates chemical action. The carbonic dioxide (CO_2) released helps in oxidizing the silicon, phosphorus, and carbon of the iron charged. In this way it is better to flux with limestone than with calcined lime (CaO).

In the basic process, the function of the slag is to transmit heat to the bath, to protect it from oxidation, to dephosphorize and desulphurize the steel, and protect the basic hearth against undue wear. It must be fluid so as not to restrict the boiling of the steel, and to flow freely out of the furnace after the steel. Should it be very thin, and black, it has an excess of sulphurous oxide (SO_2) and ferrous oxide (FeO). This will prevent dephosphorization, and decarburization.The main points are the ratio of SiO_2 and CaO and MgO in the slag. For a proper fluidity and basicity the CaO and MgO should not much exceed 55%, nor should the SiO_2 fall below 10% and the silica (SiO_2) and ferrous oxide (FeO) run about 25% to 37%.

In charging the furnace, the limestone is placed on the hearth, then the pig iron and finally the scrap on top. When all of the metal is melted, the lime is reduced and rises through the metal. The working of the heat commences with the addition of the ore to decarburize the iron. If ore is charged before the rising of the lime, the union of the oxygen of the ore and carbon of the iron is so strong as to cause minor explosions.

A general charge sheet is shown in Table 6, for basic conditions. It is based on current actual practice. Due to local conditions, principally of scrap supply, there may be some variations to suit particular localities. It, together with Table No. 1 may be used for an acid furnace with some modification of the flux and relative proportion of the pig iron and scrap.

The life of a furnace is an important matter, especially in the case of a plant equipped with but one or two furnaces.

With natural gas fuel a 20-ton basic tilting furnace in The Wellman-Seaver-Morgan Co.'s foundry has run through a campaign of 560 heats before shutting down for general repairs. Using oil the average of several campaigns give a life of 115 heats for the ports, which in this case are removable, and 250 heats for the 9-inch roof, furnace and regenerators. With care as to preparations for reconstruction, the general renewal of the brickwork need not require over 10 days' work of one shift each.

The records received from various users of Wellman furnaces show this to be an especially fast working unit. Without burdening the reader with tabulations of melting times of heats this is well illustrated in the two accompanying reports of a 20-ton basic stationary furnace. A sixteen-ton heat was made in 4 hours 10 minutes while a nineteen-ton heat was finished in five and one-half hours. Cold stock was used in both cases.

The satisfactory control of the open hearth furnace is shown by the chemical compositions ordered and obtained in regular routine operation as shown in Table No. 23. The sulphur and phosphorus content of the steel made is kept well within safe limits.

If an insufficient amount of pig iron is charged, the small amount of carbon, silicon and manganese in the steel scrap will be oxidized before the metal is ready to tap. When the bath becomes pasty, iron will oxidize freely, and the slag be too low in silicon, the ferrous oxide which will form will cut the bed of the furnace, and the oxides introduced into the metal will be hard to remove. To correct these troubles by adding pig metal causes an additional loss, by prolonging the length of the heat and the use of more fuel. An excess of pig iron is of small moment, as the carbon, silicon and manganese can be removed or boiled out by merely prolonging the heat. Ore may be added also to hasten the desiliconizing and decarburizing of the excess pig.

The slag is formed by an oxidizing of silicon and manganese which with some iron oxide causes the formation of a double silicate of manganese and calcium from the flux. A part of the silicon in the slag comes from the heat itself.

Table No. 22 is a statement, in British Thermal Units, per ton of ingots of the heat balance in open hearth work.

The melting of a charge is that operation in which is summed up the whole technical skill of a melter. On his ability thus exercised and appearing in the quality of his product depends the success or failure of the plant as a steel producer. Under his direct control and vision are the thermo-chemical reactions in the furnace, the mechanical manipulation of his equipment and the personal operations of his men. His machinery is now operated by electric, hydraulic or pneumatic power. These movements and the characteristics of his fuel and gases are capable of constant observation by recording gauges, which at the same time make a permanent continuous record of the operations. Almost at his elbow in the charging floor laboratory is his chemist who makes rapid chemical determinations of the heat being worked, in time so that he may alter his practice should it require correction. Thus every aid of mechanics and science render him instant help, and there is but scant opportunity for an "off" heat nowadays. Being freed from the harder conditions of early days, before many of these aids were available, the melter and the superintendent are enabled to go deeper into the questions of economics and thermochemistry of metallurgy, leading to the cheapening and improving of the furnace output. As the opportunity develops for the superintendent to improve his practice, his obligation to perfect his technique through study become imperative. In this way opportunity is made for bringing into action a thorough union of scientific research and the executive operating ability of a manager of men.

The cost of making steel decreases with an increase in the size of the furnace used and size of heats made. The overhead charge falls in direct ratio to the increase of tonnage while the production charges drop also but in a decreasing ratio. It has been found that the fuel used in a week's run is practically the same when a furnace is running on small heats as on large heats. For example, a certain furnace producing 800 tons of steel per week uses 360 tons of coal. This is at a rate of 900 lbs. per ton. Running heavier heats giving an output of 1066 tons, the fuel consumption drops to 675 lbs. per ton of steel. In comparing a 50-ton with a 100-ton furnace, the time for charging and melting the larger heat is longer than the smaller heat but the "refining" takes the same time. Another saving is the doing away with one tapping and patching of the furnace and using this time for melting.

When heats are poured at one time too large to be held in a single ladle the steel is tapped into two ladles standing close together at the furnace. Steel then runs from the furnace runner into a short cross runner open at both ends placed so as to deliver steel to each of the ladles. The amount going into either ladle is regulated by inclining the secondary runner towards one or the other, or by holding it horizontally when equal filling of each ladle is desired.

Table No. 7

Basic Open Hearth Operation

20-Ton Wellman Stationary Furnace

Fuel	Natural Gas	Oil
No. of Heats	10	13
Charge Ave. per Heat	42,773 Lbs.	42,630 Lbs.
Ingots Made Ave. per Heat	38,342 Lbs.	38,868 Lbs.
Scrap Made Ave. per Heat	528 Lbs.	342 Lbs.
Steel Made Ave. per Heat	38,870 Lbs.	39,210 Lbs.
Steel Made Ave. per Heat	17.35 Tons	17.5 Lbs.
Conversion Loss Ave. per Heat	9.1%	7.0%
Fuel Ave. per Heat	120,500 Cu. Ft.	956 Gals.
Fuel per Ton of Steel	6,200 Cu. Ft.	48.75 Gals.

CHARGE

Basic Pig Iron	48.8%	19,500 Lbs.
Iron Turnings	6.2%	2,500 Lbs.
Basic Steel Scrap	45.0%	18,000 Lbs.
	100.0%	40,000 Lbs.
Ferro-manganese 70%		220 Lbs.
Ferro-manganese in Ladle 80%		160 Lbs.
Ferro Silicon 10%		200 Lbs.
Ferro Silicon 50%		325 Lbs.
Ore 1400 Lbs.—Iron		700 Lbs.
Titanium in Ladle 10%		40 Lbs.
Limestone		5,500 Lbs.
Fluor Spar		150 Lbs.
Total Metal		41,645 Lbs.

SLAG

SiO_2	17.38%
Fe_2O_3	14.96%
Al_2O_3	1.18%
P_2O_5	1.64
MnO	9.93
GaO	42.45
MgO	7.75
Total	95.29

Heat Reports

Examples of open hearth operation are given in the following pages. These records are known as "heat reports." They embody a record of the metals charged and tapped, with such other operating data as will give a history of the metal and of the furnace. The practice illustrated ranges from heats of 13.6 tons to 105 tons of acid and basic product, made from hot and cold metal, using oil and producer gas and making castings for ordnance as well as general foundry work and ingots for rolling mills.

Table No. 8

14.35 Tons, Acid Foundry Casting Steel, Cold Charge, Oil Fuel

DATE Oct. 18, 1919 **REPORT HEAT NO.** 38

	MATERIAL	WEIGHT		%
CHARGE	Pig Iron	6	000	18.2
	" "			
	" "			
	" "			
	Washed Metal			
	Own Scrap	4	450	)
	Shell "	18	680	)81.8
	Misc. "	2	890	)
	Total	32	020	
ADDITIONS	Ferro Silicon ~~10%~~ 14%		590	1.8
	" ", 25%			
	" " 50%			
	" " 90%			
	Ferro Mang. 50%			
	" " 70%.			
	" " ~~80%~~ 79%		295	.9
	Silico Manganese			
	Spiegeleisen			
	Silico Spiegel			
	Aluminum—Ladle			
	" Pouring			
	Nickel			
	Manganese Ore			
	Cliff Shaft Ore			
	Ferro Chrome Ore			
	Anthracite Coal			
	Pig Iron			
	Vanadium			
Total Charge		32	905	100%
FLUXES	Iron Ore			
	Bottom Sand			
	Lime			

	HISTORY OF HEAT	Hours	Min.
TIME OF OPERATIONS	Lost between heats Making Bottom		20
	Commenced charging	12	35
	Finished charging	2	15
	Time required to charge	1	40
	Melted	3	30
	Time required to melt	1	15
	Final additions made	4	40
	Delayed in tapping		
	Cause of delay		
	Tapped	4	45
	TIME REQUIRED TO MAKE HEAT FROM "COMMENCED CHARGING" TO "TAPPED"	4	10

Boil in ladle. (Yes or No)	No
Size of nozzle	Two Inch
Condition of stopper after pouring	Good
If any trouble in pouring, give cause,	None
Weight of skull	---
Weight of spill, if any	---
Furnace working	Good
Number of heats for roof	38
" " " " " checkers	38
" " " " " port (north end)	38
" " " " " " (south end)	38
Reading of oil meter end of this heat	85584
" " " " " " last heat	84870
Gallons of oil required for this heat	714
" " " " per ton steel	43.4
T. R. D.	MELTER FOREMAN

CHEMICAL AND PHYSICAL ANALYSIS

	CAR	MANG.	SIL.	SUL.	PHOS.	CU.
Specification desired	35/45	65/75	20/25	-04	-04	
Comp. when melted						
1st preliminary test						
2nd " "						
3rd " "						
Added						
Final Composition	.40	.66	.25	.035	.039	

DESCRIPTION OF BAR	TENSILE	ELASTIC LIMIT	% ELONGATION	% CONTRACT'N	FRACTURE

Charged by

J. F. C. Chemist

Table No. 9

17.50 Tons, Acid Foundry Casting Steel, Cold Charge, Oil Fuel

DATE Oct. 10- 19

REPORT HEAT NO. 29

	MATERIAL	WEIGHT		%
CHARGE	Pig Iron	6	800	17.4
	" "			
	" "			
	" "			
	Washed Metal			
	Scrap			
	Own "	11	885	
	Shell "	14	625	79.7
	Misc. "	4	750	
	Total			
ADDITIONS	Ferro Silicon 10%			
	" " ~~20%~~ 14%		690	1.7
	" " 50%			
	" " 90%			
	Ferro Mang. 50%			
	" " 70%			
	" " 80% 79%		350	.9
	Silico Manganese			
	Spiegeleisen			
	Silico Spiegel			
	Aluminum—Ladle			
	" Pouring			
	Nickel			
	Manganese Ore			
	Cliff Shaft Ore			
	Ferro Chrome Ore			
	Anthracite Coal			
	Pig Iron			
	Vanadium			
	Iron Ore		100	.3
Total Charge		39	200	100%
FLUXES	Iron Ore			
	Bottom Sand			
	Lime			

	HISTORY OF HEAT	Hours	Min.
TIME OF OPERATIONS	Lost between heats		
	Commenced charging	10	20
	Finished charging	12	40
	Time required to charge	2	20
	Melted	2	10
	Time required to melt	1	30
	Final additions made	3	45
	Delayed in tapping		
	Cause of delay		
	Tapped	3	50
	TIME REQUIRED TO MAKE HEAT FROM "COMMENCED CHARGING" TO "TAPPED"	5	30

Boil in ladle. (Yes or No) No

Size of nozzle 2"

Condition of stopper after pouring Good

If any trouble in pouring, give cause. None

Weight of skull

Weight of spill, if any

Furnace working Good

Number of heats for roof 29

" " " " " checkers "

" " " " " port (north end) "

" " " " " " (south end) "

Reading of oil meter end of this heat 73150

" " " " " " last heat 72202

Gallons of oil required for this heat 948

" " " " per ton steel 48.4

T. R. D. MELTER FOREMAN

CHEMICAL AND PHYSICAL ANALYSIS

	CAR	MANG.	SIL.	SUL.	PHOS.	CU.
Specification desired	35/45	65/75	20/25	-04	-04	
Comp. when melted						
1st preliminary test						
2nd " "						
3rd " "						
Added						
Final Composition	.36	.70	.26	.035	.046	
DESCRIPTION OF BAR	TENSILE	ELASTIC LIMIT	% ELONGATION	% CONTRACT'N	FRACTURE	

Charged by P. M. J. C. Chemist

Table No. 10

18.60 Tons, Basic Foundry Casting Steel, Cold Charge, Oil Fuel

STEEL MELTING DEPT.—REPORT OF MATERIAL USED

DATE 12 - 17 - 1919. 19

CHARGE		**SUNDRIES**		
Pig Iron	15,000 lbs.	Nozzle Bricks	No.	1
"		Sleeve "	"	8
"		Black Leads	"	1
Scrap Cast Iron		Tar	Qts.	5
Borings, C. I.		Magnesite	Lbs.	200
Scrap Foundry	4,800	Dolomite	Lbs.	
" " Risers	8,320	Gal. Oil Used	Oil used for ladle drying as well as for O.H. furnace	960
" " Ingots				
" Steel				
" Steel	13,600			
" Steel				
" Structural		Lime		
Turnings, Steel				
Total	41,720			
Ferro Manganese	215	Limestone		4800
" Silicon	585			
" Titanium		Fluorspar		200
Spiegeleisen		Chrome Ore		
		Syndolag		900
		Iron Ore		300
		C Mn Si S Phos		
	Analysis ordered	.28 .50 .40 .025 .020		
Rod Aluminum 2 lbs.	Analysis obtained	.30 .48 .42 .024 .025		
		Time First Sent to Chemist	6:50 P. M.	
Iron Ore (Add One-Half Weight Only)		Ph. of First Test .040	Final Test .024	
TOTAL CHARGE	41,720=20.86	N. tons		
Product Ladle Steel	37,650=18.8	" " Net Castings 14.0 Tons		

Commenced Charging, 11:45 A. *M.* *Finished Charging,* 2:10 P. *M.* *Topped,* 7:50 P. *M.*

Condition of Bottom after Heat Good Time 8 hr. 05 min *Furnace No.* 1 *Heat No.* 7190

No. heats since last repair 210 SIGNED O. S. MELTER

Table No. 11

73.70 Tons, Basic Rolling Mill Steel, Hot & Cold Charge, Producer Gas Fuel

HEATS ON ROOF	24	HEATS ON PORTS	24	HEATS ON CHECKERS	24
HEATS WEEK	3	HEATS MONTH	24	FURNACE NO.	1
TONNAGE WEEK	2214	TONNAGE MONTH	1715.7	CHARGER (MELTER)	Ca.
RECORDER	C	1ST HELPER	L.	TAPPER (MELTER)	Cl

METALS CHARGED	WEIGHT
BASIC IRON HOT POURED IN FUR. 12·20 A. M	41000
" " " M	
" " " M	
" " COLD	15000
FOREIGN IRON	
MOULDS AND STOOLS	
O. H. PIT. SCRAP	
O. H. INGOT BUTTS	
B. M. CROPS	
B. M. DEFECTIVE BILLETS	
F. M. SCRAP	
FACTORY SCRAP	24100
RAILROAD SCRAP	
STIRRING RODS	100
PUNCHINGS	
SHEET AND TIN (BUNDLED)	
DRILLING TURNING-BORINGS	
PLATE SCRAP	
ROLLS-PINIONS-CASTINGS-(STEEL)	
MISC. STEEL SCRAP	
NO. 1 HEAVY MELTING	11500
% ORE	
% SCALE	
	82400
ADDITIONS IN FURNACE	
BASIC IRON HOT M	
" " COLD 7^{30} A M	5000
FERRO MN. M	2000
" SIL. 10% M	
M	
TOTAL PIG AND IRON SCRAP	61000
TOTAL STEEL SCRAP	118100
ADDITIONS IN LADLE	
FERRO MANGANESE	500
" SILICON 75%	
" " 50%	
" " 10%	
" PHOS.	
SULPHUR 175.	
TITANIUM	
ALUMINUM	
ADDITIONS IN MOULDS	
ALUMINUM	
FERRO SILICON %	
TOTAL METALLIC CHARGE	188600
INGOTS 90.9 %	165000
BUTTS %	
PIT SCRAP .3 %	500
TOTAL 91.2 %	165500
NET LOSS 8.8 %	16100
GROSS TONS OF INGOTS	73.7

ORE, FLUXES, ETC. USED	
IRON ORE CHARGED	
" " ADDED M	
" " " M	
" " " M	
" " " M	
LIMESTONE	14000
FLUOR SPAR	
SCALE	
ANTHRACITE COAL	
MAGNESITE	
DOLOMITE RAW	5000
DOLOMITE CALCINED	300
CHROME ORE	
CLAY	50
	19350

LAST HT. TAPPED	9^{20} P M
BEGAN CH'GING	9^{50} P M
FINISHED "	12^{20} A M.
MELTED	8^{35} A M
TAPPED	8^{35} A M
TIME BET. H'TS	11 H 15 M
TIME CH'GING	2 H 25 M
" MELTING	10 H 40 M
" OF HEAT	10 H 40 M
POURED BY	S
LADLE NO.	1
STOP. SLEEVES	13.
" HEADS	1.
NOZZLES	12.
STIRRING RODS	1.

SIZE	TOP CAST		BOTTOM CAST	
INGOTS	NO.	WEIGHT	NO.	WEIGHT
18X20	33	165000		
TOTAL	33	165000		
		TO PITS		BANKED

COND. OF MELT		Soft
COND. OF SLAG	MELTED	Heavy
	BEFORE TAPPING	
COND. OF BATH AFTER ADDING	FERRO MN. M	
	% SIL. M	
COND OF METAL	TAPPING	Hot
KIND OF TAP		Good

LADLE COND. AFTER POURING	SPOTS	RING	SKULL	CLEAN
	X			

	CARBON	TIME
FRACTURES	8	
"		
"		
"		
"		
"		

	CARB	MN.	PHOS.	SUL.	SIL.
LAB. PRELIM					
" " M					
" " M					
" " M					
TOT. POINTS ADD.		40		70	
"					
"					
LAB. FINAL	13	64	.015	.130	
ORDERED	10-15	60-70	.04	110-130	
VARIATION					
ACTION IN M'LDS.	open				
" " ROLLS					

Table No. 12

73.80 Tons, Basic Rolling Mill Steel, Hot & Cold Charge Producer Gas Fuel

HEATS ON ROOF	43	HEATS ON PORTS	43	HEATS ON CHECKERS	43
HEATS WEEK	5	HEATS MONTH	4	FURNACE NO.	1
TONNAGE WEEK	337	TONNAGE MONTH	267.4	CHARGER (MELTER)	O'N
RECORDER	C	1ST HELPER	L	TAPPER (MELTER)	McM

METALS CHARGED	WEIGHT
BASIC IRON HOT (POURED IN FUR.) 12·25 M	6000
" " " 1·05 M	25700
" " " M	
" " COLD	55000
FOREIGN IRON	
MOULDS AND STOOLS	
O. H. PIT. SCRAP	
O. H. INGOT BUTTS	
B. M. CROPS	17100
B. M. DEFECTIVE BILLETS	
F. M. SCRAP	9400
FACTORY SCRAP	
RAILROAD SCRAP	
STIRRING RODS	
PUNCHINGS	24100
SHEET AND TIN (BUNDLED)	
DRILLING-TURNING-BORINGS	17300
PLATE SCRAP	
ROLLS-PINIONS-CASTINGS-(STEEL)	
MISC. STEEL SCRAP	22800
NO. 1 HEAVY MELTING	
60 % ORE	4200
% SCALE	
ADDITIONS IN FURNACE	
BASIC IRON HOT M	
" " COLD M	
FERRO MN. M	150
" SIL. 10% M	
Spiegel M	450
TOTAL PIG AND IRON SCRAP	86700
TOTAL STEEL SCRAP	94900
ADDITIONS IN LADLE	
FERRO MANGANESE	
" SILICON 75%	
" " 50%	450
" " 10%	
" PHOS.	
SULPHUR	
TITANIUM	
ALUMINUM	
ADDITIONS IN MOULDS	
ALUMINUM	5
FERRO SILICON	
TOTAL METALLIC CHARGE	182655
INGOTS 90.5 %	165300
BUTTS %	
PIT SCRAP .9 %	1500
TOTAL 91.4 %	166800
NET LOSS 8.6 %	15855
GROSS TONS OF INGOTS	73.8

ORE, FLUXES, ETC. USED			
IRON ORE CHARGED		LAST HT. TAPPED	5^{05}_{a} M
" " ADDED M		BEGAN CH'GING	10^{15}_{a} M
" " " M		FINISHED "	1^{05}_{p} M
" " " M		MELTED	9^{55}_{p} M
" " " M	7000	TAPPED	10^{45}_{p} M
LIMESTONE	14000	TIME BET. H'TS	17 H 40 M
FLUOR SPAR	2000	TIME CH'GING	2 H 50 M
SCALE		" MELTING	11 H 40 M
ANTHRACITE COAL	360	" OF HEAT	12 H 30 M
		POURED BY	S
MAGNESITE		LADLE NO.	4
DOLOMITE RAW		STOP. SLEEVES	13
DOLOMITE CALCINED		" HEADS	1
CHROME ORE		NOZZLES	12
CLAY	50	STIRRING RODS	
	23410		

SIZE	TOP CAST		BOTTOM CAST	
INGOTS	NO.	WEIGHT	NO.	WEIGHT
18X20	29	165300	Box Spring Steel Made	
TOTAL	29	165300		
		TO PITS		BANKED

COND. OF MELT		
COND. OF SLAG	MELTED	Heavy
	BEFORE TAPPING	Creamy
COND. OF BATH AFTER ADDING	FERRO MN. M	
	% SIL. M	
COND OF METAL	TAPPING	Fair
KIND OF TAP		Good

LADLE COND. AFTER POURING	SPOTS	RING	SKULL	CLEAN

	CARBON	TIME
FRACTURES	106	9:55
"	91	10:55
"	83	10:40
"		
"		
"		

LAB. PRELIM	CARB	MN.	PHOS.	SUL.	SIL.
" " M					
" " M					
" " M					
TOT POINTS ADD.	17	05			
"					
"					
LAB. FINAL	101	45	.016	.040	.09
ORDERED	95-100	35-45	.04	.045	07-09
VARIATION					
ACTION IN M'LDS.					
" " ROLLS					

Table No. 13

80.8 & 82.50 Ton, Basic Rolling Mill Steel, Hot & Cold Charge, Producer Gas Fuel

________________ STEEL CO.

OPEN HEARTH NO.

HEAT NUMBERS ____ FURNACE NO. ____ TONS SINCE REBUILDING. 6385

TONS MONTH. 3073 HEATS ON PORTS. 82 NO. HEATS ON CHECKERS 82

CONDITION OF FURNACE. O.K. BOTTOM. O.K. ROOF. O.K. VALVES. O.K.

NO TONS WORKED YEAR. 2 AVERAGE TONS PER TURN. 82 TONS PER YR. 30651

CHARGE.	WEIGHT.	FLUXES ETC. USED.	WEIGHT.
IRON HOT. TIME POURED IN FCE.	LBS.	LIME STONE RAW	LBS. 18600
" " 3:40 A.M	15000	LIME	4600
" " 3:48 "	15000	FLOURSPAR	1000
" " 5:04 "	14000		
" " 5:10 "	14000	BOTTOM REPAIRS.	
" " 8:35 "	12000	MAGNESITE.	300
8:44 "	11000	DOLOMITE CALCINED	6900
10:12 A.M.	5000		
TOTAL IRON	86000		
HEAVY ST. SCRAP CROPS BUTTS ETC.	239300		
BUNDLE TIN SCRAP	16100		
TOTAL STEEL.	255400		
BASIC IRON HOT.	86000		

CUSTOMER. STRUCTURAL MILL A.

HEAT NO.	ANALYSIS	CAR	SIL.	PHOS	SUL.	MANG	NIC.
609	ORDERED	13/20					
	ACTUAL	20		14	40	40	

CUSTOMER. STRUCTURAL MILL B.

610	ORDERED	16/18				32/40	
		18		14	43	40	

HEAT NUMBERS		HEAT NO.	HEAT NO.	HEAT NO.	HEAT NO.	
ADDITIONS IN LADLE FERRO MANG. %		LBS. 800	LBS. 1000			
FERRO SILICON %		70	70			
SPIEGEL		800				
COAL.			50			
ADDITIONS IN MOULDS-ALUMINUM.		3	3			
TOTAL METALLIC CHARGE.						
PRODUCT & PRACTICE	TOTAL PRODUCT OF CHARGE	LBS.	LBS.			
INGOT WEIGHT %		181,200	185,475			
BUTTS %		½ = 2,850				
OPERATION		TIME OF HEAT.				
CHARGING		3 HOURS.				
MELTING		6 "				
REFINING		2 HRS. 30 MIN.				
TAPPING.		10 MIN.				
TOTAL HEAT TIME		11 HRS. 50 MIN.				
SIZE NOZZLE.		2"	2"			

Table No. 14

96.00 Tons Basic Rolling Mill Steel, Hot & Cold Charge, Producer Gas Fuel

OPEN HEARTH _ HEAT RECORD.

O.H. DEPT. — STEEL CO.— —10-30-1919.

HEAT NO. TIME CHARGED. 1:20 P.M. TAPPED. 12:50 A.M TIME IN FCE. 11:30

HOW HEAT MELTED. HARD. MELTER

CHARGE.	NET WEIGHT.						%
HOT IRON.							
COLD IRON.	1	2	3	1	0	0	48^{1}
EXTRA PIG COLD.							
CAR WHEELS.			2	4	0	0	0^{9}
CAST SCRAP.							
HEAVY MELT							
BLOOM CROPS		5	6	0	0	0	21^{9}
FOREIGN CROPS.		3	3	4	0	0	13^{0}
SHEET BAR CROPS.							
JOBBING MILL.							
COMP. SHEET.		3	4	6	0	0	13^{5}
SIDES AND ENDS.							
TURNINGS.			4	5	0	0	1^{7}
INGOTS AND BUTTS.							
PIT SCRAP.							
STIRRING RODS.				5	2	5	
REJECTED SLABS.							
ANNEALING SCRAP BURNT.							
COLD STRIP SCRAP.							
HOT STRIP SCRAP.							
BALL SCRAP.							
FERRO MANGANESE.			1	4	0	0	
10% SILICON							
50% SILICON							
FERRO. PHOS.							
SULPHUR							
ALUMINUM							
COPPER							
							99^{1}
TOTAL METALS.	2	5	5	9	2	5	
IRON ORE			4	0	0	0	
LIMESTONE.		2	5	0	0	0	
DOLOMITE BURNT.			8	0	0	0	
FLOOR SPAR.			1	5	0	0	
CHROME ORE.							
SYNDOLAG							
ANTHRACITE COAL.							
COKE							
DOLOMITE RAW							
TOTAL FLUXES.		3	8	5	0	0	

PRODUCTION.

	NO	SIZE	WEIGHT	%
INGOTS	35	20/22	216000	84^{4}
INGOTS			96 TONS.	
BUTTS.			3000	1^{2}
PIT SCRAP			12800	5^{0}
TOTAL PROD.			231800	90^{6}

ANALYSIS SPEC. 200

CARBON .09	.08-.12
MANGANESE .48	.40-.55
SULPHUR .027	.040 OR UNDER.
PHSPHORUS .015	.040 OR UNDER.
SILICON	
COPPER.	

TIME RECORD.

TIME PATCHING. :30
BEGAN CHARGING. 1:20 P.M. 10/30
FINISHED CHARGING. 4:40 P.M 10/30
TIME CHARGING. 3:20
TIME TAPPED. 12:50 A.M. 10/31
TIME MELTING. 8:10
TIME OF HEAT. 11:30

FUEL RECORD.

COAL PER TON STEEL.
OIL PER TON STEEL.
STIRRING RODS USED. 3
STOPPER SLEEVES 16
STOPPER HEADS USED. 1
NOZZLES USED. 1
NO. HEATS ON ROOF. 25
NO. HEATS ON PORTS. 111
NO. HEATS ON CHECKERS. 111
NO. HEATS SINCE LAST REPAIR TO FURNACE. 25

REMARKS.

Table No. 15

One Week's Operation—Basic Furnaces

12—100-Ton O. H. Furnace Plant

..................Works, ...Co., ...1919

CHARGE PER FURNACE

	Total—1 Week	Per Heat	%
Hot Metal	1,128,540 lbs.	86,810 lbs.	37.0
Pig Metal	260,500 lbs.	20,039 lbs.	8.5
Scrap Steel	1,648,000 lbs.	126,770 lbs.	54.1
Ore, ½ of 19,500 lbs.	9,500 lbs.	731 lbs.	.4
Total Metal	3,046,540 lbs.	234,350 lbs.	100.0
Total Metal	1,360 tons	104.6 tons	
Limestone	358,200 lbs.	27,556 lbs.	
Limestone per pound of Metal		0.12 lbs.	

TIME PER HEAT

Charging Hot Metal	1 hr. 31 min.
Charging Pig and Scrap	1 hr. 47 min.
Charging Total	3 hrs. 18 min.
Melting and Refining	7 hrs. 02 min.
Repairs	1 hr. 22 min.
Total per Heat	11 hrs. 42 min.
Time per ton of charge	6.7 min.
Charging Time—day shift	3 hrs. 32 min.
Charging time—night shift	3 hrs. 14 min.
Furnaces in Plant	12
Furnaces in Operation	9
Week of seven days	168 hrs.
Idle Time—Sunday	16 hrs.
Working Time	152 hrs.
Heats per Furnace per week	13

Table No. 16

105 Tons, Basic Rolling Mill Steel—Hot Bess. Duplex Metal Charge Producer Gas Fuel

Record of Open Hearth No.

Furnace No. Jan. 26, 1920

Material	Buggy No.	No. of Boxes		Metallic Contents Weight	Rec'd from Stock and Cars	Remarks
Bessemer Blown Metal				270000		
Total						

Tapped Previous Heat 12:15 A.M.
Began Charging 1:10 A.
Finished Charging 1:40 A.
Melted
Time Tapped 3:15 A.

Time of Heat 3 Hrs. Min.

Melted about Carbon
Slag
Extra Metal Added
Temp. When Tapped

Additions in Furnaces			
Ferro. Mang.	80%		
" Sil.	10%		
" Sil.	50%		

Additions in Ladle			
Ferro. Mang.	65%	xx	1800
" Sil.	10%		
" Sil.	50%		400
" Phos.			800
Total Metallic Charge			
Product Ingots	%		
Butts & Cond. Ingots	%		
Pit Scrap	%		
Light Ladle Skulls	%		
Loss	%		
Total			

Ore-Flux, Etc.	
Limestone	8000
Limestone	
Ore	
Ore	
Fluor Spar	
Coal Anthracite	
Roll Scale	4000

Bottom Repairs	
Dolomite	
Magnesite	
Chrome Ore	

1st Helper Tw
Foreman Ge
Date Jan. 26, 1920
Plant No. # O.H.

Heat No. 9----

Description of Ingots

No.	Size	Kind of Mould	Weight
	20x20	Rail	

Analysis

Aim.	8-12	35-50	05-06	05-	025-05
Det.	09	37	057	046	024

CORRECT:

UWW
Weighmaster.

XYZ
Dept. Clerk.

Furnace drained at each tap—105 tons per heat
Average tap to tap-3hrs. 15min.

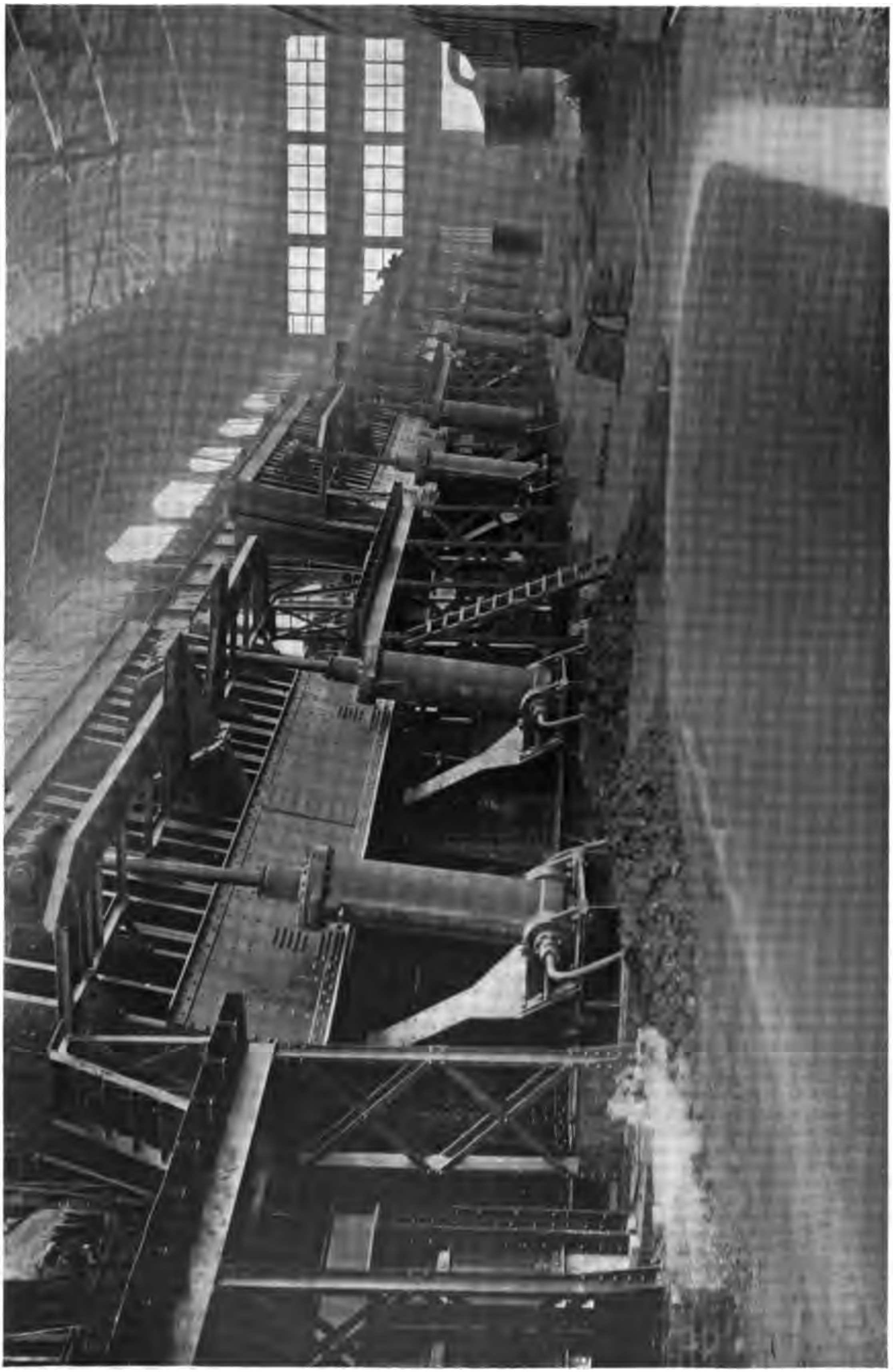


Figure 20—FOUR 50-TON WELLMAN HYDRAULIC TILTING OPEN HEARTH FURNACES

Installed at The American Steel & Wire Co.'s Plant, Cleveland, Ohio. The perfect alignment of the furnace structures under operating conditions as shown above reveals the adequacy of the Wellman construction.

Open Hearth Practice at the Watertown Arsenal U. S. Army

Gun Forging Castings

The operating conditions of an open hearth furnace making ordnance steel are somewhat different from ordinary steel making. The time the charge is kept in the furnace before tapping is longer than usual and the furnaces are run hotter. The "gas" turns or idle week ends are rather long as they extend from about 5 P. M. Saturday until 11 P. M. on Sunday night. No ladle daubing is used on the steel ladles except a trifling amount around the nozzle, due to the undesirability of having it spall off and dropping into the steel.

A 15-ton Wellman tilting furnace and two thirty-five-ton Wellman stationary furnaces are in service. They are acid lined and use fuel oil.

In the last run of the 15-ton furnace, the roof lasted 425 heats. During this time the central portion of the backwall was repaired once, the front wall three times, the end walls and oil burner ports once. The checker chambers were cleaned out at the end of the 275th heat, and 40% of the checkers were renewed. The roof was good for 50 to 75 heats more but the furnace was dismantled for re-erection in the new foundry building.

35-ton Furnace

The campaign of the roof was 450 heats. During this time the central portion of the backwall was repaired twice, the front wall, end walls, gas or oil ports once.

After the 275th heat the checker chamber was cleaned out and 30% of the checkers replaced.

Although the brickwork, except that of the roof, could have stood about 100 heats more yet at the end of the run of 450 heats the furnace was rebuilt. Included in this renewal were the checkers, up-takes, end and side walls and roof.

The 15 and 35-ton ladles will average 75 heats per lining.

The organization of the working force per turn is as follows:

	1 Furnace men	2 Furnaces men	3 Furnaces men
Stockyard craneman	1	1	2
Charging machine operator			
Stockers	2	5	7
Melter		1	1
1st helper	1, taps his own heats	2	3
2nd helper	2	2	3
3rd helper	1	2	3
Ladleman		2	
Steel pourer			
Ladleman's helper			1
Total	7 men	16 men	23 men

Every effort is made to melt down as fast as possible and the furnace run as hot as it will stand from time charge is in until damper is lowered. Bath should be hot enough to take the limestone quickly, and also the ore at end of 45 to 60 minutes. The addition of limestone can be much higher if need be, as no harmful action has been found even with slag running over 10% CaO.

At the same time as damper is lowered, the mushroom valve, or valve regulating cold air passing to checker chamber is also lowered somewhat, to assist in producing a reducing flame over the bath. This reducing flame will slowly cool down the furnace and the bath. The furnace should be operated hot previously to this period so that, in spite of the cooler flame, the steel will be hot enough to permit SiO_2 being reduced to Si, and also hot enough to tap and hold in the ladle for a period of 15 minutes or longer.

Fracture tests are taken from time to time for judging the carbon content, and as soon as the melter believes the silicon is beginning to "pick-up," the silicon is judged from the same test by observing the contour of the top surface of the test while setting or chilling in the cast iron test mold.

Table No. 17

History of 35-ton Acid Heat

Watertown Arsenal

35-ton Open Hearth Acid Furnace Charge

Pig Iron	27.4%
Plate Scrap	33.6%
Cast Steel Scrap	34.8%
Mang. Steel Scrap	3.7%
Fe. Sil. 50%	.5%
	100.0%

		Car		Mang.		Sil.		Sul.		Phos.	
	Wt.	%	Wt.	%	Lot	%	Wt.	%	Wt.	%	Wt.
Pig Iron lbs.	22000	3.60	792.0	.65	143.0	2.20	484.0	.035	7.70	0.35	7.70
Plate lbs.	27000	.20	54.0	.50	135.0	.13	35.1	.035	9.45	.025	6.75
C. S. Scrap lbs.	28000	.35	98.0	.70	196.0	.27	75.6	.040	12.60	.045	12.60
Mn. St. Scrap lbs.	3000	1.20	36.0	12.00	360.0	.30	9.0	.080	2.40	.080	2.40
			980.0		834.0		603.7		32.15		29.45
Fe. Si. 50% lbs.		400					200.0				
Total lbs.	80400	1.22		1.03		1.00		.040		.037	

Time melting down—5 hrs. 15 min.
Carbon when melted—1.08.
450 lbs. Limestone added as soon as melted.
400 lbs. Lump Hematite Iron Ore added 1 hr. after melted.
200 lbs. Lump Hematite Iron Ore added 3-5-60 hrs. after melted.
5 hrs. 35 min. after melted—slag—dark brown but solid.
6 hrs. 15 min. after melted—slag—light brown but solid.
6 hrs. 45 min. after melted—damper lowered.
7 hrs. 35 min. after melted—slag—dark yellow.
8 hrs. 35 min. after melted—slag—light yellow and glossy.
10 hrs. 25 min. after melted—fracture test shows approx. .20 Sil.
10 hrs. 35 min. after melted—75 lbs., 50% Fe. Si. added to bath, or approx. 0.05 Sil.
11 hrs. 5 min. after melted—925 lbs. Fe. Mn. (70.5% Mn.—6.30%C.) added.
11 hrs. 20 min. after melted—furnace tapped (76000 lbs.) (C. S. No. 3)

Resultant Analysis of Product

C.	Mn.	Sil.	S.	P.
0.37	0.70	0.26	0.040	0.040

Carbon added by Fe. Mn.	0.076	Sil. in product	0.26
Carbon obtained from Fe. Mn.	0.07	Sil. added	0.05
Mang. added by Fe. Mn.	0.858	Sil. pick up	0.21
Mang. obtained from Fe. Mn.	0.700		

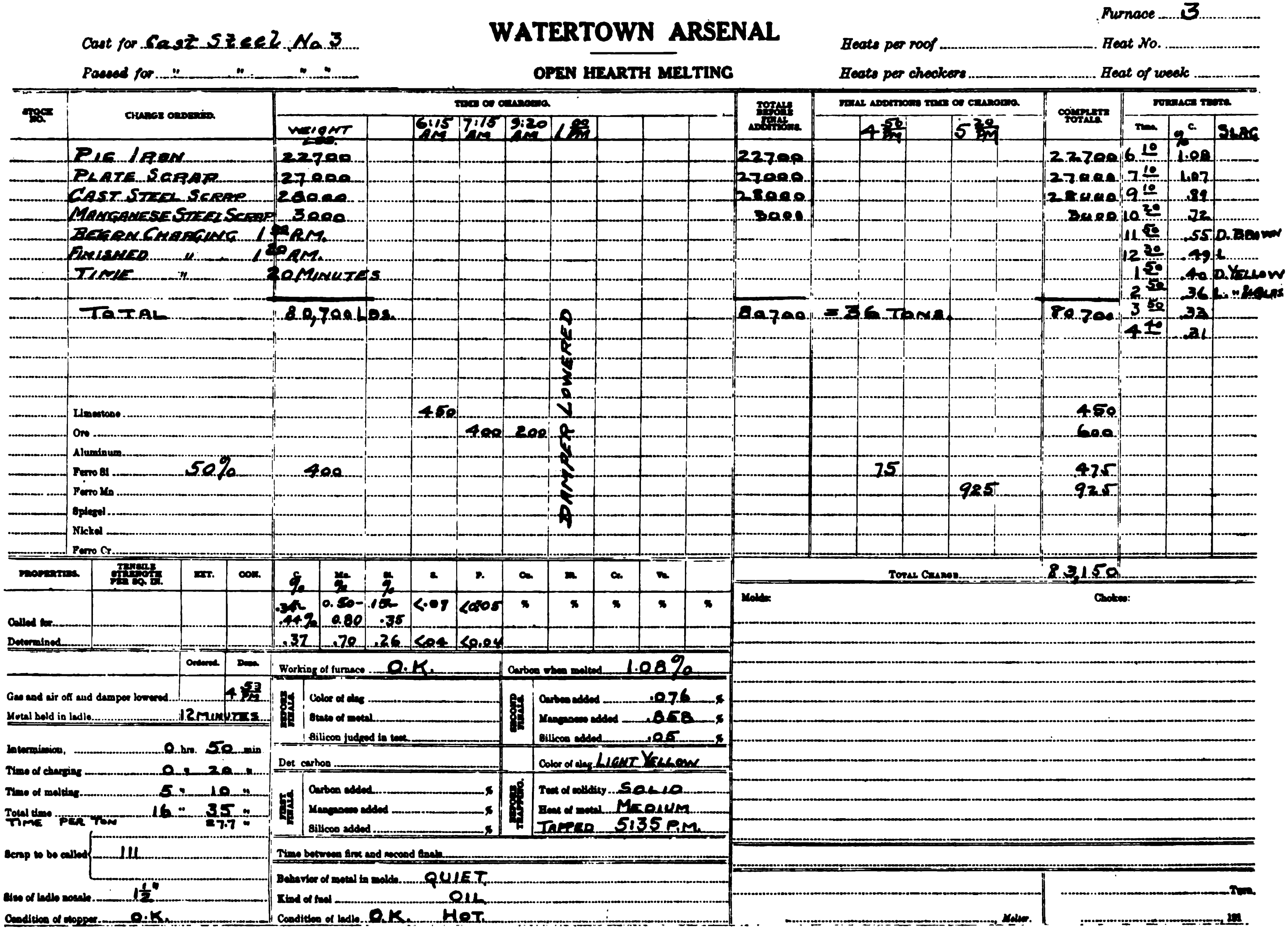
Carbon drop—last 10 points,—210 min. or 1 point (.01) carbon in 21 min.
Fuel oil consumed beginning charging to tap—54.3 gals. per net ton in ladle.

Analysis of slag after additions of alloys and just before tapping.

Silica	(SiO_2)	55.00
Alumina	(A_2O_3)	3.80
Iron Oxide	(FeO)	22.85
Lime	(CaO)	3.53
Mang. Oxide	(MnO)	14.50
Sul. and Phos.	(S & P)	Traces
Magnesia	(MgO)	0.32
		100.00

Table No. 18

37.00 Tons, Acid Ordnance Casting Steel, Cold Charge, Oil Fuel



WATERTOWN ARSENAL

OPEN HEARTH MELTING

Cast for Cast Steel No 3

Passed for " " " "

Furnace 3

Heats per roof .... Heat No. ....

Heats per checkers .... Heat of week ....

Stock No.	Charge Ordered.	Time of Charging. Weight Lbs.		6:15 AM	7:15 AM	9:20 AM	1^{00} PM				Totals before Final Additions.	Final Additions Time of Charging.	4^{50} PM		5^{20} PM	Complete Totals.	Furnace Tests. Time.	% C.	Slag
	Pig Iron	22700									22700					22700	6^{10}	1.08	
	Plate Scrap	27000									27000					27000	7^{10}	1.07	
	Cast Steel Scrap	28000									28000					28000	9^{10}	.89	
	Manganese Steel Scrap	3000									3000					3000	10^{20}	.72	
	Began Charging 1^{00} A.M.																11^{50}	.55	D. Brown
	Finished " 1^{20} A.M.																12^{30}	.49	L
	Time "	20 Minutes															1^{50}	.40	D. Yellow
																	2^{50}	.36	L. " Yellow
	Total	80,700 Lbs.					Damper Lowered				80700	= 36 Tons				80700	3^{50}	.32	
																	4^{10}	.31	
	Limestone			450												450			
	Ore				400	200										600			
	Aluminum																		
	Ferro Si 50%	400											75			475			
	Ferro Mn														925	925			
	Spiegel																		
	Nickel																		
	Ferro Cr.																		

Total Charge 83150

Properties.	Tensile Strength per sq. in.	Ext.	Con.	C. %	Mn. %	Si. %	S.	P.	Cu.	Ni.	Cr.	Va.	
Called for				.34–.44%	0.50–0.80	.15–.35	<.07	<.005	%	%	%	%	%
Determined				.37	.70	.26	<.04	<0.04					

Molds: Chokes:

	Ordered.	Done.
Gas and air off and damper lowered		4^{53} PM
Metal held in ladle	12 Minutes	

Intermission, 0 hrs. 50 min

Time of charging 0 " 20 "

Time of melting 5 " 10 "

Total time 16 " 35 "

Time per Ton 27.7 "

Scrap to be called 111

Size of ladle nozzle $1\frac{1}{2}$"

Condition of stopper O.K.

Working of furnace O.K.

Carbon when melted 1.08%

Before Finals:

Color of slag ....

State of metal ....

Silicon judged in test ....

Det carbon ....

First Finals:

Carbon added .... %

Manganese added .... %

Silicon added .... %

Second Finals:

Carbon added .076 %

Manganese added .858 %

Silicon added .05 %

Color of slag Light Yellow

Before Tapping:

Test of solidity Solid

Heat of metal Medium

Tapped 5:35 P.M.

Time between first and second finals ....

Behavior of metal in molds Quiet

Kind of fuel Oil

Condition of ladle O.K. Hot

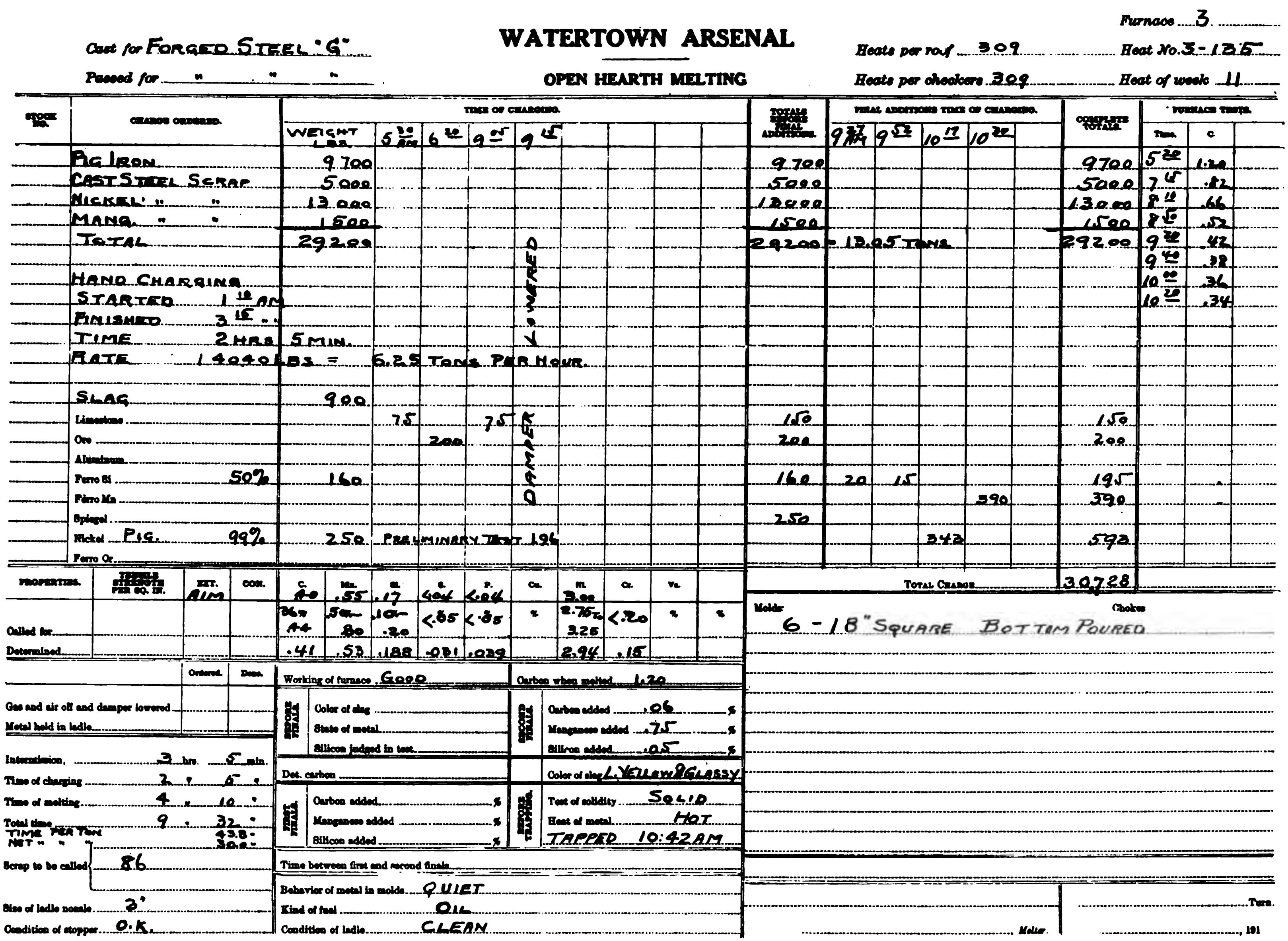
.... Melter.

.... Turn.

.... 191

Table No. 19

13.6 Tons, Acid Ordnance Casting Steel, Cold Charge, Oil Fuel



WATERTOWN ARSENAL

OPEN HEARTH MELTING

Cast for FORGED STEEL "G"
Passed for " " "
Furnace 3
Heats per roof 309
Heat No. 3-135
Heats per checkers 309
Heat of week 11

Stock No.	Charge Ordered.	Time of Charging. Weight Lbs.	5^{30} AM	6^{20}	9^{05}	9^{15}				Totals before Final Additions.	Final Additions Time of Charging. 9^{37} AM	9^{52}	10^{17}	10^{22}		Complete Totals.	Furnace Tests. Time.	C	
	PIG IRON	9.700								9.700						9700	5^{20}	1.20	
	CAST STEEL SCRAP	5.000								5000						5000	7^{45}	.82	
	NICKEL " "	13.000								13000						13000	8^{11}	.66	
	MANG. " "	1.500								1500						1500	8^{50}	.52	
	TOTAL	29.200				LOWERED				29200 = 13.05 TONS						29200	9^{20}	.42	
																	9^{40}	.38	
	HAND CHARGING																10^{00}	.36	
	STARTED 1^{10} AM																10^{20}	.34	
	FINISHED 3^{15} " "																		
	TIME 2 HRS 5 MIN.																		
	RATE 14040 LBS = 6.25 TONS PER HOUR.																		
	SLAG	900																	
	Limestone		75		75	DAMPER				150						150			
	Ore			200						200						200			
	Aluminum																		
	Ferro Si 50%	160								160	20	15				195			
	Ferro Mn													390		390			
	Spiegel									250									
	Nickel PIG. 99%	250	PRELIMINARY TEST 1.96										342			592			
	Ferro Cr																		
										Total Charge						30728			

Properties.	Tensile Strength per sq. in.	Ext.	Con.	C.	Mn.	Si.	S.	P.	Cu.	Ni.	Cr.	Va.	
		AIM		.40	.55	.17	<.04	<.04		3.00			
Called for				.36 to .44	.50 to .80	.10 to .20	<.05	<.05	%	2.75 to 3.25	<.20	%	%
Determined				.41	.53	.188	.031	.039		2.94	.15		

Molds: 6 - 18" SQUARE BOTTOM POURED
Chokes

	Ordered.	Done.
Gas and air off and damper lowered		
Metal held in ladle		

Intermission 3 hrs. 5 min.
Time of charging 2 " 5 "
Time of melting 4 " 10 "
Total time 9 " 32 "
TIME PER TON 43.8 "
NET " " 30.0 "
Scrap to be called 86
Size of ladle nozzle 2"
Condition of stopper O.K.

Working of furnace GOOD
Carbon when melted 1.20

Before Finals:
Color of slag
State of metal
Silicon judged in test

Second Finals:
Carbon added .06 %
Manganese added .75 %
Silicon added .05 %

Det. carbon
Color of slag L. YELLOW & GLASSY

First Finals:
Carbon added %
Manganese added %
Silicon added %

Before Tapping:
Test of solidity SOLID
Heat of metal HOT
TAPPED 10:42 AM

Time between first and second finals
Behavior of metal in molds QUIET
Kind of fuel OIL
Condition of ladle CLEAN

Melter.
Turn.
, 191

All tests taken during the last two hours before tapping should pour cleanly from the spoon, and not emit any sparks during pouring, or solidifying in the test mold. The slag should be easily pushed back from surface of the metal in the spoon and "sticky" enough that it will not run out of the spoon with the metal. The slag within the furnace during this period should be what some melters call "blobby." The bubbles made by the gas evolved from the bath should rise slowly before breaking, and subside gradually.

The above rough outline of the practice at this arsenal is one found suitable in making steel for gun forgings, and is necessary in order to insure the steel passing the transverse tests. While it is easy to pass tensile test requirements specified for castings with a lesser degree of refinement of the molten steel, it would seem advantageous to also make castings for gun carriages of as good steel as the melter is capable of producing.

Furthermore, it has been found that when the steel is tapped in this "dead melt" condition, no trouble is had from castings cracking during the period when they are cooling in the mold—even the complicated castings often found in ordnance work.

The following temperatures of steel tapped from the open hearths are quite reliable:

Table No. 20

Furnace and Ladle Temperatures

	Acid O. H. Heats		Temps. °Cent.
Judged by Eye	At Spout	From Ladle	Drop
Cold	1569	1504	65
Cold	1583	1500	83
Cold	1600	1518	82
Medium	1617	1538	79
Medium	1617	1532	85
Medium	1617	1530	87
Hot	1630	1534	96
Hot	1630	1543	87

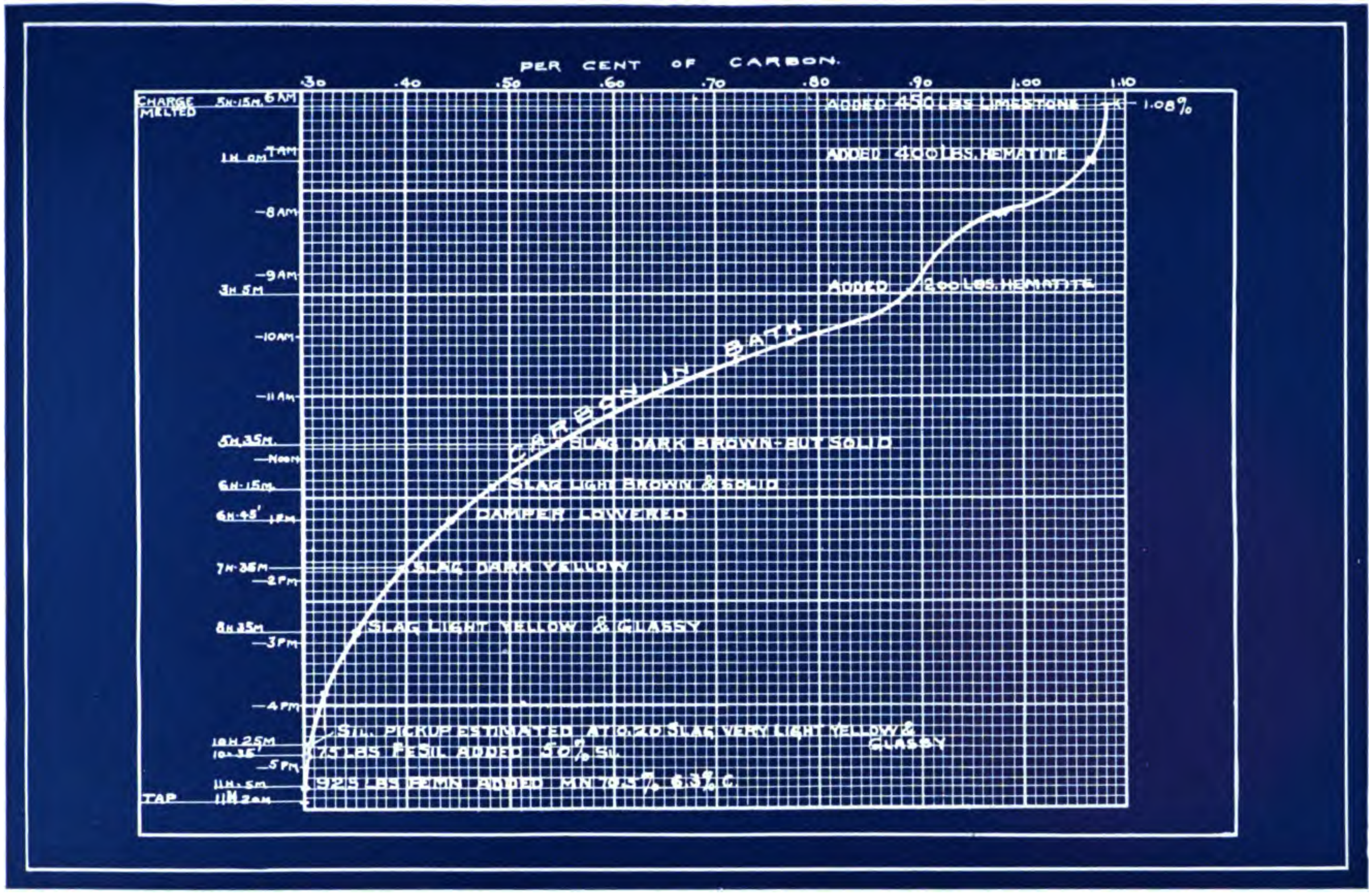


Figure 21—DIAGRAM OF CARBON ELIMINATION OF HEAT REPORTED IN TABLE NO. 17.

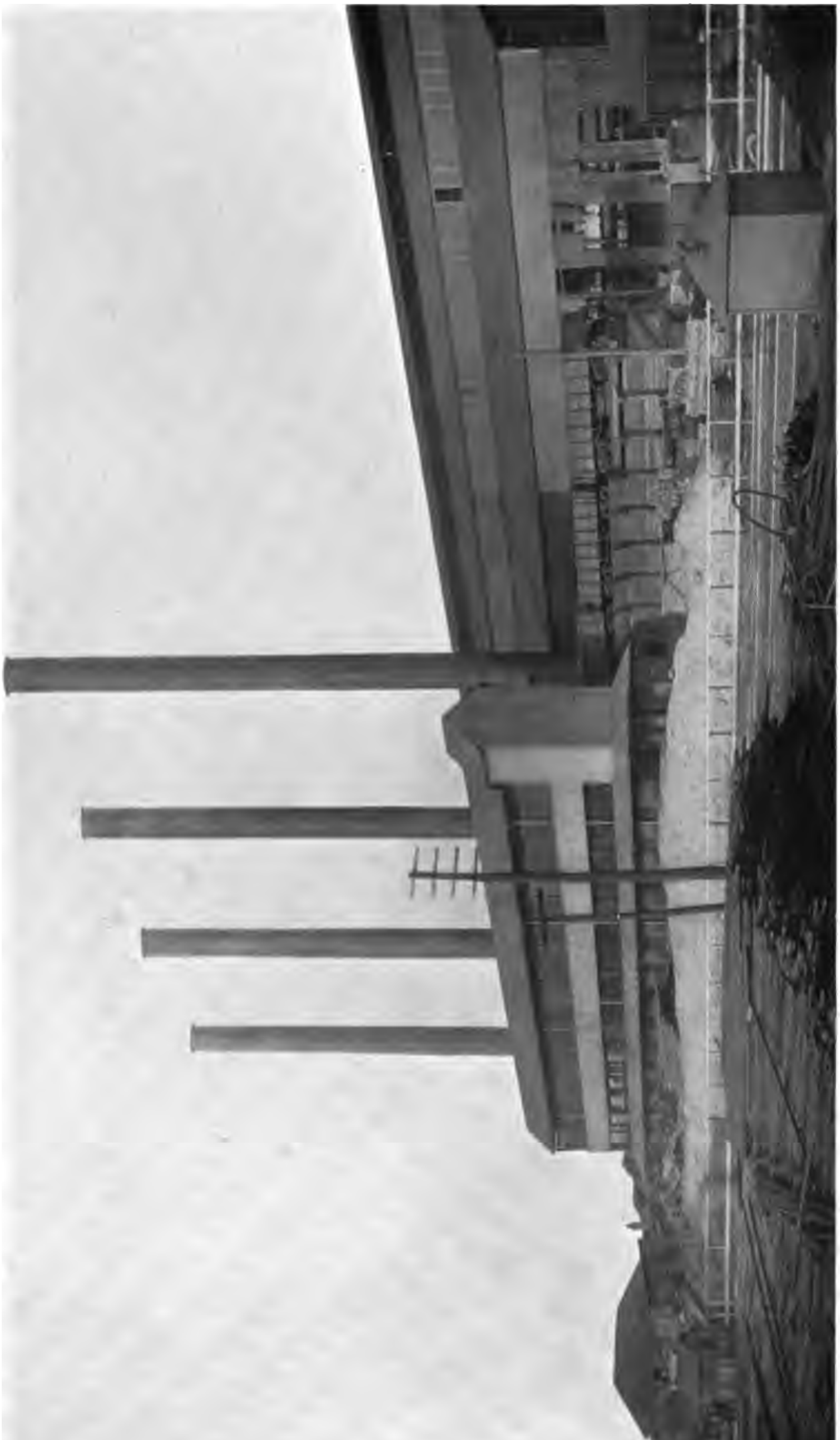


Figure 22—AMERICAN STEEL & WIRE CO.'S OPEN HEARTH PLANT, CLEVELAND, O.

This view shows the gas producer building with overhead coal storage bins, and coal supply track closely adjacent to the furnaces, so as to avoid loss of the sensible heat of the gas by radiation.

CHAPTER VI

Efficiency of the Open Hearth

In an open hearth furnace using producer gas 29.4% of the total heat available is utilized in the steel making operations of reducing the charge, making slag and melting the metal and heating it to the tapping temperature.

The heat supplied by electricity for an electric steel furnace may be generated by water power, by steam or gas engines.

For a steam power plant using high pressure turbine driven generators under test conditions the maximum efficiency is 19%. Under normal operating conditions this will drop to about 15% of the potential energy of the fuel, delivered as heat in the furnace.

In the case of large gas engines direct connected to the generators the maximum thermal efficiency in the furnace is approximately 17%.

In the first instance the fuel generator is the simple and efficient gas producer which delivers in one operation into the furnace 92% of the original energy of the coal, even when using low grade coal.

The efficiency of the electric furnace in utilizing thermal energy is low because of the accumulation of losses accompanying each step in the operation.

These losses are cumulative, running through each step of converting potential heat of the fuel into gas or steam, thence into power and electricity to be finally reduced at the electrodes to the lowest form of energy, viz.: heat.

An elaborate, complicated, and expensive system is required for this chain of operations, including boilers, or gas generators, steam or gas engines direct connected to electric generators, transmission lines, transformers, switchboards, controllers and electrodes.

The cost of electric smelting is capable of reduction by eliminating the isolated power plant driving moderate sized generators. This is possible by the location at the coal pit mouth of great gas producer plants feeding gas to gas engines direct connected to large generators. In this way cheap low grade coals can be used efficiently, leaving the higher priced coals to be available for other uses.

Table of the costs of steel in the ladle shows in a striking manner the relative economy of the principal methods of steel making. The figures of this table taken in connection with those of Table No. 21, bring out the combination in the open hearth furnace of low producing cost and high excellence of steel made.

It is probable that a highly effective arrangement for a moderate sized steel foundry would be to install both an acid and a basic open hearth furnace. At times steel foundries operating a basic furnace and neighboring machine shops will accumulate a stock of acid scrap which may have to be shipped away, and, at the same time, basic scrap brought into the locality to feed the furnace or vice versa. An acid and a basic installation would eliminate this expense.

Table No. 21

Cost per ton of Steel—in the Ladle

2000 lbs. = 1 Ton

Items	Cost Per Ton	Open Hearth Foundry				Electric Furnace Castings		Acid Bessemer Converter Castings		Crucible Castings	
		Acid		Basic							
		Weight Lbs.	Cost	Weight Lbs.	Cost	Weight Lbs.	Cost	Weight Lbs.	Cost	Weight Lbs.	Cost
Pig Iron	$30 00	300	$ 4.50	1040	$15.60			1580	$23.70		
Gate Heads	14.00	660	4.62	660	4.62	660	4.62	660	4.62	660	4.62
Scrap	12.50	1080	6.75	350	2.19	1330	8.31			1330	8.31
Defective Castings	50.00	20	50	40	1.00	10	.25	20	.50	10	.25
Ferro Alloy	40.00	30	.60	35	.70	12	.24	35	.70	12	.24
Total Metal		2089	16.97	2123	24.11	2012	13.42	2295	29.52	2012	13.42
Operating Cost			7.25		7.20		20.00		6.50		35.00
Cost—Steel in Ladle			24.22		31.31		33.42		36.02		48.42
Cost of Castings			$37.35		$48 10		$51.50		$55.50		$74.70
Credit Heads			4.62		4.62		4.62		4.62		4.62
Net Cost—Steel in Ladle		1 Ton	$32.73		$43.48		$46.88		$50.88		$69.78

Yield of castings 65% of steel in ladle in sound castings

Table No. 22

Open Hearth "Heat Balance"

Per ton of Ingots

Size of Heat in Tons	60		50		45		30		
Location	United States		United States		England		Germany		Holland
Fuel	Producer Gas		Natural Gas						
	Btu.	%	Btu.	%	Btu.	%	Btu.	%	%
Sensible Heat in Gas	830,000	10.1							
Combustion of Fuel	5,793,000	70.7	5,743,000	79.2	10,360,000	88.3	6,677,000	75.6	68.0
Sensible Heat in Charge	503,000	6.1	364,000	5.0	7,000		764,000	8.6	14.6
Oxidation of Metals	1,073,000	13.1	1,149,000	15.8	1,360,000	11.7	1,387,000	15 8	17.4
Total Heat Available	8,199,000	100.0	7,256,000	100.0	11,727,000	100.0	8,828,000	100.0	100.0
HEAT DISTRIBUTION									
Absorbed in Reduction	751,000	9.2	271,000	3.7	790,000	6.7	730,000	8.3	10.6
Absorbed in Slag Making	373,000	4.5	322,000	4.4	895,000	7.7	639,000	7.2	3.9
Absorbed in Steel Melting	1,289,000	15.7	1,380,000	19.0	2,120,000	18.0	1,414,000	16.0	20.5
Absorbed in Useful Work	2,413,000	29.4	1,973,000	27.1	3,805,000	32.4	2,783,000	31.5	35.0
Lost by Radiation, Etc.	2,021,000	24.6	2,073,000	28.6	4,422,000	37 6	3,414,000	38.7	42.6
Lost in Waste Gases	3,756,000	46.0	3,210,000	44.3	3,500,000	30.0	2,631,000	29.8	22.4
Total Expended	8,199,000	100.0	7,256,000	100.0	11,727,000	100.0	8,828,000	100 0	100.0
REGENERATORS									
Delivered to Regenerator	5,616,000	68.4	3,410,000	47.0					
Returned to Furnace	4,448,000	54.2	3,193,000	44.0					
Efficiency of Regenerator		79.0		93.0					

The Heat Balance of the Open Hearth Furnace

The heat balance of a furnace is a statement of the heat supplied, and expended, with an account of its disposition. The purpose is to determine what portion is usefully consumed in carrying on the metallurgical operations desired and to find the extent and nature of the heat losses. In this way the possibilities of improved operation and increased economies are indicated in character and amount. For instance, the extent to which water cooling of portions of the furnace may be carried without extravagance is shown in this way.

The principle of the Carnot cycle conceived of in the study of heat engines is applicable to the open hearth furnace. In the form of an equation, this principle is

$$E=\frac{T_1-T_2}{T_1}=\frac{H_1-H_2.}{H_2}$$

In which E is the efficiency of the apparatus T_1 and T_2 are the initial and final temperatures of the working substance while H_1 and H_2 are the total heats delivered to and rejected from the apparatus. The values of temperature and heat are reckoned from absolute zero.

The value of E is independent of the substance subjected to the action of heat.

The efficiency of the apparatus is the ratio of the heat used to the total heat available, and depends solely upon these two quantities.

The heat supplied to the furnace is the sensible heat of the fuel at its temperature of supply plus the heat of combustion minus the heat of vaporization of the resultant water vapor. The fuel consists of the extraneous fuel such as gas or oil fed into the furnace together with such metals and metalloids of the charge as are oxidized, during the time of the "melt" or "heat." The amount of heat available is calculable from the thermochemical properties of the fuel, and cannot be increased by any operation such as regeneration, or recuperation.

The ideal furnace satisfying all thermodynamic and metallurgical requirements would consist of a hearth and combustion chamber enclosed in a substance impermeable to the passage of heat. The fuel would be a pure combustible oxidized by undiluted oxygen. The proportions and form of the furnace would be such as to secure a maximum heat absorption by the metal of the bath, and a discharge of waste gases at atmospheric temperature. The efficiency obtainable would be the maximum.

As in the case of a heat engine, such perfection is unattainable. In the case of the open hearth furnace, the efficiency is lowered by the following losses:

1. Radiation and conduction through the furnace walls, etc.
2. Absorption of heat in the uncondensed highly heated water vapor resulting from hydrogen combustion.
3. Absorption of heat by the nitrogen of the air accompanying the oxygen used in combustion.
4. Absorption of heat by the large excess of air delivered to the furnace above that actually required for oxidation.
5. Too great an application of the idea of water-cooling portions of the furnace such as ports, buckstays, etc.
6. Heat carried into the atmosphere by the waste gases.
7. Delivery into the furnace of wet materials of the charge.

These losses are so great, that in a furnace of simply a hearth and combustion chamber an intensity of heat necessary is not attainable. The difficulty is overcome by extending the furnace in principle by the addition of a regenerator, whereby the furnace is enabled to use a greater proportion of the heat brought into it by the fuel, than otherwise.

In steam engineering, an exact parallel is found in the reduction of waste heat by the use of feed water heaters or fuel economizers placed in the flue to the stack.

Therefore the efficiency of the open hearth furnace is the ratio of the heat charged into it from the fuel to the heat usefully used in the reduction of the charge according to the following equation:

$$E = \frac{H_1 - H_2}{H_1}$$

in which

H_1 = Sensible heat of the fuel, plus its heat of combustion, plus the sensible heat of the air entering the furnace apparatus at its normal atmospheric temperature, minus the heat of vaporization of the water vapor both entering the furnace and resulting from the combustion of hydrogen in the fuel.

H_2 = Heat losses of all kinds.

$H_1 - H_2$ = Heat utilized in reducing, refining and heating to the tapping temperature of the metal of the "heat" plus the heat utilized in slag making and heating.

Thus the regenerator action can be considered in no other way than of reducing the heat losses, i. e., the amount of H_2. The regenerator, organically, is an extension mainly of the furnace "laboratory," whereby the metal of the bath absorbs a larger part of the heat than it would do otherwise.

Table No. 23

Basic Open Hearth Steel Analyses

Heat No.	Authority		Carbon %	Manganese %	Silicon %	Sulphur %	Phosphorus %	Oxygen %
29	Vulcan Iron	Ordered	.35 to .40	.65 to .75	.20 to .25	.040	.040	
	Works	Made	.36	.70	.26	.035	.046	
38	Vulcan Iron	Ordered	.35 to .40	.65 to .70	.20 to .25	.040	.040	
	Works	Made	.40	.66	.25	.035	.039	
A	Wellman-Seaver-	Ordered	.25	.55	.40	.030	.030	
	Morgan Co.'s	Made	.26	.58	.42	.025	.022	
6805	W-S-M Foundry	"	.58	.46	.47	.016	.041	
6823	W-S-M Foundry	"	.21	.40	.44	.019	.019	
6827	W-S-M Foundry	"	.22	.39	.37	.018	.018	
6828	W-S-M Foundry	"	.21	.40	.37	.018	.019	
B	W-S-M Foundry	"	.25	.47	.43	.020	.019	
C	W-S-M Foundry	"	.24	.59	.36	.025	.010	
D	W-S-M Foundry	"	.21	.49	.396	.020	.018	
	Penna. Steel Co., Campbell		1.09		.02	.027	.008	
	Steelton		.72		.02	.027	.008	
	Penna. Steel Co., Campbell		.31		.02	.020	.008	
	Steelton		.24		.02	.027	.008	
	Penna. Steel Co., Campbell		.31		.02	.021	.008	
	F. W. Harboard		.10	.217	Trace	.034	.004	
	F. W. Harboard		.108	.214	Trace	.033	.005	
	F. W. Harboard		.305	.147	.0097	.0027	.0077	
	Stead (F. W. Harboard)		.02 to .03	.05 to .07	.0000	.010 to .020	.008 to .010	.02 to .05

CHAPTER VII

Selection of Type of Furnace

In the duplex process the open hearth furnace is used for desiliconizing, partial decarburizing (and, in a basic open hearth furnace, dephosphorizing) the metal. The refining is completed in the electric furnace. The electric furnace is of a smaller capacity than the open hearth. As the greater part of the conversion of the charge into steel is accomplished in the open hearth, the working of the electric furnace is comparatively rapid, this part of the operation being finished in about two hours.

In the production of alloy steels, and "high speed" tool steel open hearth furnaces of moderate size, that is of 15 to 20 tons capacity, are used, while the electric furnaces used in conjunction run from 2 to 6 tons in size. For such work a rapid open hearth is desired. This is obtained by using a comparatively shallow bath. Another object gained by such a bath is overcoming to a considerable extent the settling to the bottom of the heavy alloys used, such as nickel and tungsten.

In the triplex process a preliminary elimination of silicon and of carbon down to about 1% is accomplished by blowing the "hot metal" in a Bessemer converter before it is charged into the open hearth. The triplex process lends itself to steel making on a great scale, in which a large tonnage of steel is produced. In the higher development of the process open hearth furnaces up to 200 tons capacity are used while 300 tons capacity is under consideration. It would not be economically possible to conduct operations of such magnitude without the use of tilting furnaces.

Two large steel mills in the Pittsburgh district of the same cost afford a comparison between the two types of furnaces, figures for which are given in the columns for plants "A" and "B" in Table No. 24.

Table No. 24

Comparison of Stationary and Tilting Furnace Plants

Plant	A	B	C
Type of furnaces	Stationary	Tilting	Tilting
Number of furnaces	10	5	8
Capacity of furnaces, each	60 tons	180 tons	180 tons
Capacity of furnaces, each, monthly	4,800 tons	6,000 tons	6,000 tons
Capacity of furnaces, total monthly	48,000 tons	30,000 tons	48,000 tons
Hearth area of furnaces, each	378 sq. ft.	576 sq. ft.	576 sq. ft.
Hearth area of furnaces, total	3,780 sq. ft.	2,880 sq. ft.	4,608 sq. ft.
Heats of furnaces, daily, each	2 to 3	5 to 6	5 to 6
Product per sq. ft. hearth area per month	12.7 tons	10.4 tons	10.4 tons
Ratio of monthly total output	100%	62.5%	100%
Ratio of plant investment	100%	100%	160%

A third column of figures for plant "C" is given for a hypothetical plant of tilting furnaces of a productive capacity equal to the stationary furnace plant "A." For an equal tonnage of steel production the probable cost of a tilting furnace plant is 60% greater than that of the stationary furnace plant "A."

A stationary furnace plant has the advantage over a tilting furnace plant in the cheaper cost of installation, and hence interest charges, of great output and a minimum liability to delays from mechanical causes. These features are important factors in large mills in which the continuous hot metal process from blast furnaces to the finishing mills is used, and where the steel user does not specify the additional step of electric furnace finishing.

Stationary furnaces of the larger sizes are equipped with slag spouts (although not always) in addition to the tapping hole runner. When so equipped, the first and highly phosphatic slag in a basic furnace may be drawn off from the furnace before tapping time, and reabsorption of the phosphorus by the steel avoided. Thus this type of furnace may be used with a basic lining in melting high phosphorus charge, quite as well as the tilting type. Nevertheless many operators prefer the tilting furnace for basic working, because of the easy slag removal by tilting the furnace.

A great advantage of the tilting furnace is the perfect ease of tapping, not only the slag, but chiefly the metal, quickly, at such times and in whatever quantities desired for the subsequent working of the metal either in the electric furnace or the casting of ingots or the filling of moulds in foundry work. In such a furnace the steel runner is "luted" or closed with a lightly tamped refractory, which is cleaned out of the runner with a trifling effort.

The tapping hole of a stationary furnace is closed by ramming into place a plug of dolomite and tar topped off with sand and clay. As this plug is baked quite hard by the furnace heat, a hole must be drilled through it by hand or power drill. At times the first metal in running out freezes in the hole, and requires additional drilling, with extreme hard labor and loss of much valuable time.

The patching of the walls of a tilting furnace is done with comparative ease. During this work the furnace is tilted slightly so as to retain the fresh refractories in place till sufficiently sintered, to stay in place.

A tilting furnace is especially adapted for a mill or foundry in which steels of varying compositions or casting temperatures are needed in different quantities at short intervals. This is because pouring of metal from the furnace can be stopped quickly by merely tilting its spout upward, instead of having to break the stream of running metal by a plug of clay or dolomite as in a stationary furnace.

Under present conditions of high phosphorus stock, the best practice generally indicates a basic lining, especially for a tilting furnace.

CHAPTER VIII

Fuels Used by the Open Hearth Furnace

As in the Bessemer converter a considerable portion of the heat is supplied to the open hearth furnace by the combustion of metalloids in the charge. According to Table No. 22, this ranges from 12% to 17% of the total heat of the operation, but this is an expensive source of heat being bought at the price of pig iron and scrap rather than of coal or gas. The balance of the heat is furnished by one of the following fuels:

1. Natural Gas.
2. Fuel Oil.
3. Tar.
4. Coke Oven Gas.
5. Pulverized Coal.
6. Electric Energy.
7. City Illuminating Gas.
8. Producer Gas.

The fuel which can satisfy, at a minimum cost, the following requirement is most suitable. These qualifications are a uniform quality of chemical composition, high calorific capacity, freedom from sulphur, also from ash, and yielding a flame high in radiant heat, and which is readily perceptible to the melter.

Natural Gas

Stands high as an open hearth fuel. It requires no regeneration, and is piped directly to the port opening into the furnace from the walls. This economizes in construction cost and obviates leakage from the gas to the air chamber in the regenerator. It is free from sulphur.

The calorific value runs from 970–1010 Btu. per cubic foot. But its supply is restricted to certain small fields and its quantity is decreasing and price rapidly increasing.

A steel maker using natural gas, but not owning gas wells, must pay at the present time about 20 cents per 1000 cubic feet for gas. With a fair average gas consumption of 5000 cu. ft. per ton of steel the fuel cost is $1.00 per ton. In some cases where wells are owned by "parent" companies, gas is sold to the steel mills at about 8 cents per M. ft., equivalent to 40 cents per ton of steel, which with necessary collateral expenses brings the fuel cost to 55 cents per ton.

Fuel Oil

Is either crude petroleum or the residuum after a partial distillation of the crude oil has yielded the more valuable light oils of the gasoline and kerosene series. On account of its wide use in the arts its cost is high. It has a considerable variation in calorific value, and in composition, and in physical qualities such as viscosity. Owing to its source of supply being generally distant from steel works, a considerable expense is incurred in building storage tanks, which, from the nature of their contents, constitute a fire hazard. In open hearth work about 40 gallons and upwards per ton of steel is required, according to the size of the furnace and "heat" melted.

Tar

Is denser than petroleum oil and requires for vaporization more heat than oil. It

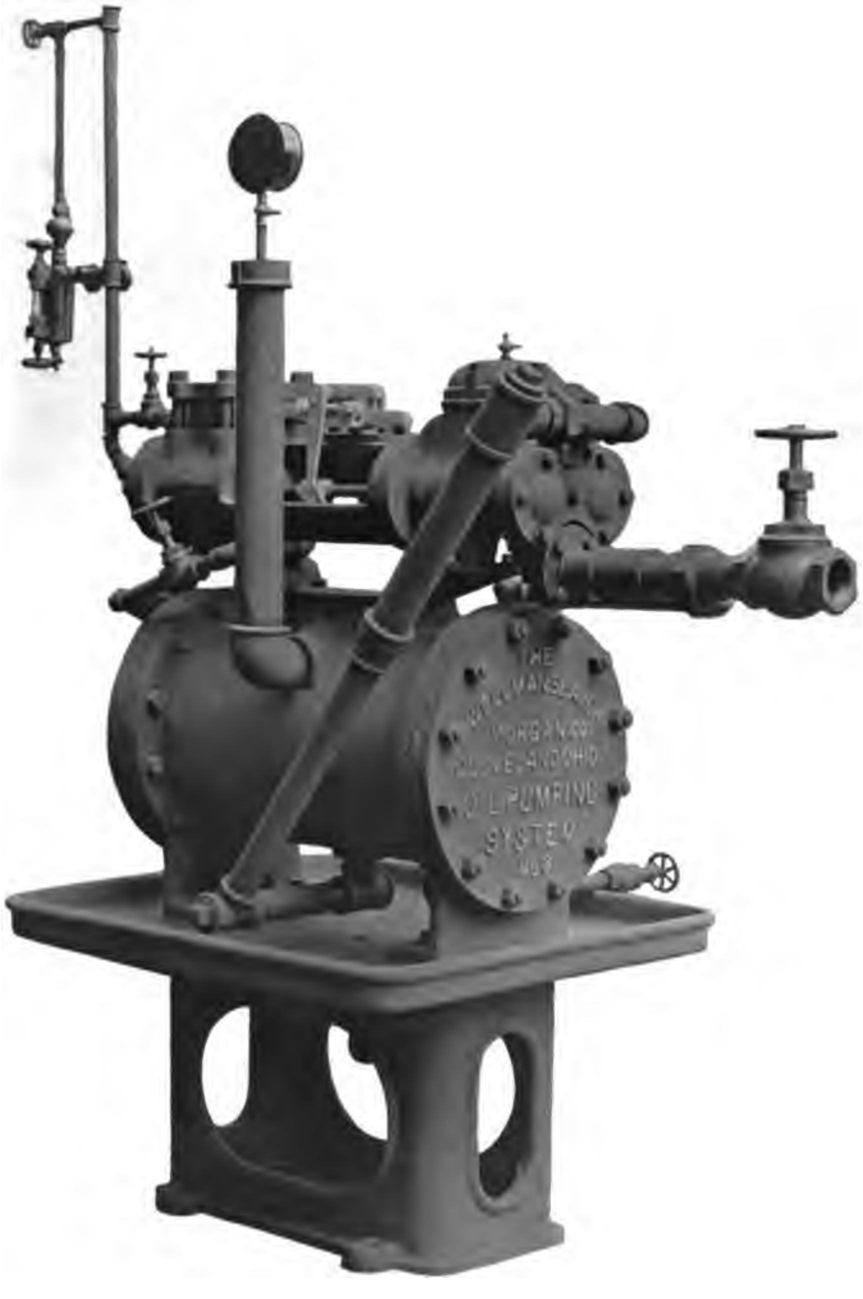


Figure 23—WELLMAN OIL PUMPING SYSTEM FOR OIL BURNING FURNACES

is an item of manufacture of by-product coke plants. On account of cost, its use as an open hearth fuel is confined to the locality of its place of production. It is similar to oil as a fuel, and its calorific value is high. The burners are quite simple in form and operation. It is atomized by air or steam at a pressure of 70 to 80 pounds gauge pressure.

Furnaces using fuel oil or tar must be provided with spare burners, as those in use may burn off, calling for immediate replacement.

Coke Oven Gas

Is a suitable fuel for furnaces located adjacent to a by-product coke plant. Its calorific value runs from 450 to 500 Btu. per cubic foot. When heated in a regenerator, there is a loss of 3% in hydrogen and 15% in methane (CH_4), accompanied by a rise of 10% in carbon monoxide (CO) resulting in a net loss in heating power of the gas. Coke oven gas gives a high flame temperature, amounting to over 3360° F. As this gas tends to rise to the furnace roof and produces so high a temperature, it is necessary to protect the roof by using steep ports, sloping so as to throw the gas down towards the hearth.

Pulverized Coal

This fuel has had its greatest development and success in firing cement kilns. The ash enters into and becomes a part of the clinker made, without injury to the cement clinker. It is thus easily disposed of and presents no difficulties such as arise when burning pulverized coal in a steel furnace. In the latter case a part of the ash adds to the slag while the removal of such ash as is deposited in the ports, regenerators and flues presents a troublesome problem not yet adequately solved. Coal must be used which is high in volatile matter, low in sulphur and does not contain over 8% ash. It must be ground exceedingly fine so that 97% will pass a 100 mesh sieve and 85% go through a 300 mesh. To prevent absorption of sulphur by the bath complete combustion must occur before the flame strikes the bath. The flame produced is very hot and should tend to shorten the usual melting time. The high flame temperature is accompanied by a more rapid wear of the furnace roof and port brickwork. This process requires a fuel consumption of approximately 500 lbs. of coal per ton of ingots, in good practice.

The substance of the matter is that pulverized coal for open hearth work demands a high grade coal, low in sulphur and low in ash. It is a matter of general knowledge that the coals now being mined do not always run low in these two items unless coal is washed, which increases its cost. Therefore a careful examination of the fuel supply must be made and certain delivery of desirable coal be assured when considering this form of fuel.

The apparatus required consists of coal bins, magnets to separate out iron, crushers, pulverizers, conveyors, storage bins, spouts and a comparatively simple form of burner, together with a compressed air installation to give air for spraying at 80 pounds pressure. As with gas or oil, the furnace must be fired at each end, alternately.

Electric Power

Conservation of coal by utilization of water supplies is one of the beneficent possibilities in the use of electricity. Conversion of the free energy in a waterfall requires an expensive permanent installation for power house and transmission lines. Therefore, the net cost of electricity to the consumer approximates that obtained from a steam plant. The cheapest hydro-electric power available for steel furnaces costs about $25.00 per year per horse-power, or $\frac{1}{3}$ cent per kw. hour. An electric furnace will consume about 600 kwh. per ton of steel. At a more probable cost of 1 cent per kwh., the electric energy will cost $6.00 per ton of ingots. Electricity consumed as heat costs approximately $2.50 per 1,000,000 Btu. Its use is justified more from the metallurgical standpoint than as an economical source of heat.

City Illuminating Gas

It is possible under some conditions this may be considered for open hearth fuel, though not yet so used. Having a calorific power of from 550 to 650 Btu. and at a price of $0.50 per M. cubic feet it will cost $5.00 per ton of steel, being thus about on a par with electricity.

Producer Gas

Throughout the metallurgical industry, with the exception of the blast furnace, the most important of all fuels is producer gas. The cause of this superior position is due to the following factors;—relatively small capital investment needed, simplicity of construction and operation, the small amount of attending labor and of unskilled quality required in gas making, the reliability of operation and output, the ease of response to variations in amount demanded by the consumer, and the very high thermal efficiency in converting the calorific equivalent of the coal into heat delivered to the steel furnace.

Another and highly important advantage of producer gas as a fuel for metallurgical and other furnaces is the production of good gas from poor or average coals as now mined. This is possible, and is daily being done when the coal is gasified in a producer equipped with the following mechanically operated features:

1st. A mechanical feed.
2nd. A mechanical poker.
3rd. A mechanical ash plow and scraper.

The long evolution in the making of gas producers has culminated in the Wellman mechanical gas producer equipped with the latest of heavy duty mechanical coal feeds—a machine of the highest mechanical and thermal efficiency embodying all of the favorable qualities above mentioned.

The relative value of fuels for open hearth work is given in Table No. 25.

Table No. 25

Cost of Open Hearth Fuels

	Hughes Mechanical Producer Gas	Pulverized Coal	Natural Gas	Coke Oven Gas	Petroleum Oil	Tar	Electric Power	Blue Water Gas	City Illuminating Gas
Installation for One Furnace	$25000.	$31000.	$ 2000.		$ 2500.	$ 2500.	$65000.		
Fuel per Ton of Ingots......	510 of Coal	500 of Coal	5500 Cu. Ft.	11200 Cu. Ft.	43 Gals.	43 Gals.	600 K.W.H.	18000 Cu. Ft.	10000 Cu. Ft.
Fuel Calorific Value—Btu. per Unit................	13400 per Lb. of Coal		1070 Cu. Ft.	580 Cu. Ft.	142,250 Gals.	138,000 Gals.	3412 K.W.H.	330 Cu. Ft.	650 Cu. Ft.
Fuel Calorific Value per Ton Ingots..................	6,834,000	6,700,000	5,885,000	6,496,000	6,117,000	5,934,000	2,047,000	5,940,000	6,500,000
Fuel Cost per Ton, M. Cu. Ft., Gal., Kw. Hr........	$4.00	$4.00	$0.30	$0.16	$0.06	$0.06	$0.01	$0.35	$0.70
Fuel Cost Operating Labor..	0.57	0.73			.005	.005			
Total Fuel and Op. Labor...	4.57	4.73	0.30+	0.16+	0.065	0.065	0.01+	0.35+	0.70+
Cost per Ton of Ingots.....	1.042	1.055	1.65	1.79	2.80	2.80	6.00	6.30	7.00
Cost per Million Btu......	0.152	0.158	0.28	.28	0.46	0.47	2.93	1.06	1.08

Total Fuel Cost = Above + [Plant Investment, Maintenance, Depreciation, Plant and General Overhead].

Table No. 26

Cost of Producer Gas

Included in the Table are Costs of Fuel, Power, Repairs, Maintenance, Labor, Supervision, Interest, and Depreciation—But not interest on value of site, or taxes.

STEERE ENGINEERING CO.

Producer Gas Costs Per 1000 Cu. Ft. for Coal Cost per First Column			Cost of Other Fuels to Obtain Same Number of Btu.'s as Given by Producer Gas, With Coal at Prices Named in First Column							
			Natural Gas Per 1000 Cu. Ft.		Fuel Oil Per Gallon		Coal Gas or Carburetted Water Gas Per 1000 Cu. Ft.		Blue Gas Per 1000 Cu. Ft.	
Cost of Coal per Ton at the Plant	Hot Raw Gas at Offtake	Clean Cold Gas	Hot Raw Gas	Cold Clean Gas	Hot Raw Gas	Cold Clean Gas	Hot Raw Gas	Cold Cl'n Gas	Hot Raw Gas	Cold Cl'n Gas
$2.00	3.13c	4.15c	23.7c	31.7 c	2.91c	3.86c	12.6 c	16.72c	6.45c	8.59c
2.50	3.55	4.57	26.9	34.67	3.00	4.25	14.3	18.40	7.34	9.45
3.00	3.96	4.98	30.1	37.84	3.69	4.64	16.6	20.09	8.20	10.32
3.50	4.38	5.40	33.3	41.01	4.08	5.03	17.65	21.77	9.07	11.18
4.00	4.72	5.82	36.3	44.18	4.46	5.42	19.3	23.45	9.92	12.05
4.50	5.21	6.24	39.5	47.35	4.85	5.81	21.0	25.13	10.78	12.91
5.00	5.63	6.66	42.7	50.52	5.24	6.20	22.7	26.82	11.65	13.78
5.50	6.05	7.08	45.9	53.69	5.63	6.59	24.35	28.50	12.5	14.64
6.00	6.46	7.49	49.1	56.85	6.01	6.97	26.0	30.18	13.36	15.50

Above table based on 100% load factor for 308 days of 24 hrs. per year.

HEATING VALUES USED

Producer Gas	145. Btu. per cu. ft.
Natural Gas	1100. Btu. per cu. ft.
Fuel Oil	135000. Btu. per gal.
Coal Gas or Carburetted Water Gas	585. Btu. per cu. ft.
Blue Gas	300. Btu. per cu. ft.

C = Cost of 1000 cu. ft. producer gas.
A = Cu. ft. gas used daily.
B = Days per week of operation.
R = Cu. ft. gas hourly rated capacity.
T = Cost figure in above table and 100% load.

$$C = T + \left[\frac{400\,R}{AB}\right] - 2.38$$

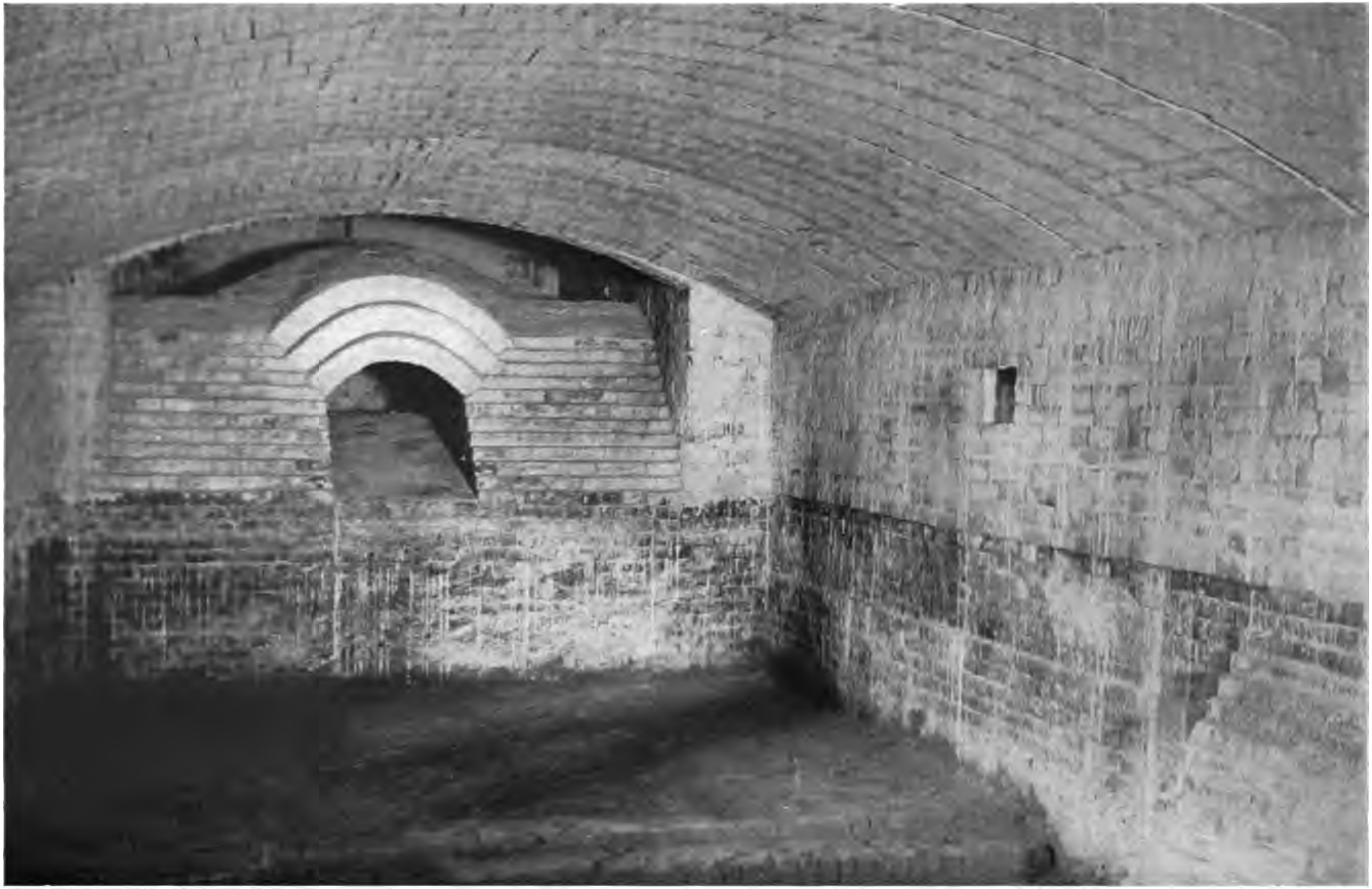


Figure 24—INTERIOR VIEW OF A WELLMAN FURNACE

This photograph was taken in the interior of a Wellman Open Hearth Furnace, prior to "burning in" the bed. It shows ports, roof, walls and the bottom. The ports are designed for producer gas.

CHAPTER IX

Melting and Gas Tending

The melting of the charge in a small furnace differs from that of larger units chiefly in the rapidity with which the stock melts, and a shorter time of refining. In a small furnace the melt may take place in an hour, while in a 65-ton furnace four hours are occupied in melting and in basic work getting lime up.

In this connection it may be of service to mention the materials on which the "melter" exercises his skill in basic practice, as given in Table No. 27.

Table No. 27

Open Hearth Charge and Product

Material	Parts of Charge %	Weight per ton of steel made Lbs.
Hot metal	36.0	873
Cold pig	15.0	376
Chills	1.0	17
Moulds	1.0	20
Total pig metal	53.0	1286
Pit scrap	3	64
Ingot butts	2	46
Turnings	2	41
Sheet scrap	4	99
Steel scrap	35	833
Ferro-manganese	0.5	16
Ferro silicon	0.5	
Total steel scrap	47	1099
Total metal charged	100	2385
Product		
Steel	94.0	2240
Pit scrap	2.9	70
Loss	3.1	75
Total	100.0	2384
Auxiliary Charge		
Coal		4
Ore and Cinder, equivalent to 54 lbs. metal		108
Fluor Spar		4
Aluminum		0.5
Limestone		119
Magnesite for patching		1
Raw Dolomite		100
Chrome Ore		10

Considering as a part of the metal charged the iron of the ore amounting to approximately 54 lbs. per ton of steel, the ratio of charge to steel produced is 94.0% and the ratio to ingots is 91.1%.

The quality and amount of materials required to make a ton of steel are more or less firmly fixed and, together with the auxiliary additions for recarburizing, are beyond the control of the melter, whose province lies in controlling the fuel and regenerated air to maintain at all times the furnace temperatures and character of the flame.

Combined volume and suction gas meters, whose readings are visible and also recorded permanently, should be used as a guide and check as to the pressure and quantity of the gas used and times of reversal of the gas and air valves. The intelligent use of these instruments will go far in perfecting the skill of the melter. Much of the alleged superiority of some European steels is due to the intelligent control of the metallurgical operations on the part of the melter.

In a well designed plant valves, dampers, charging doors, and other operating parts of the furnace are worked and controlled from a stand conveniently placed on the charging floor where the manipulation is accomplished by opening or closing small easily worked pressure valves or controlling switches. The ports, doors, jambs, etc., are water cooled and thereby made more lasting

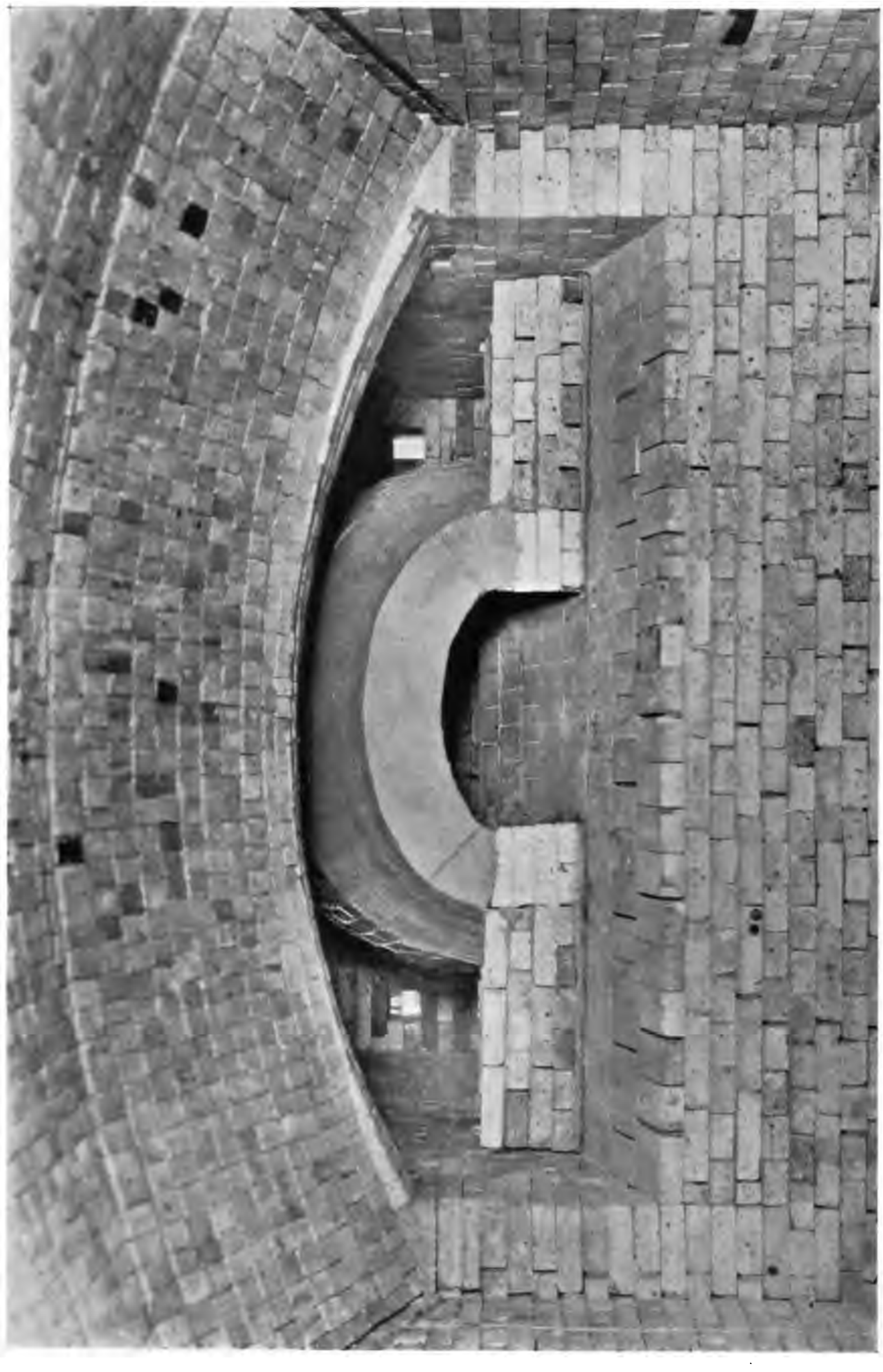


Figure 25—INTERIOR OF A WELLMAN OPEN HEARTH FURNACE

This is a producer gas fired furnace. Long life of the roof is made possible by the arrangement of the ports, whereby a comparatively cool layer of air is interposed between the roof and the incandescent fuel flame.

and cutting down minor repairs. Thus the manual labor and minor cares of the melter are eased and he can devote more attention to his metallurgical duties.

The proper planning of the gas and air ports is an important part of a furnace design. This ensures a combustion so controlled as to throw into the bath a maximum of heat by radiation and conduction. The admission of air must be such as to interpose protection to the roof from the flame and secure a perfect mixture with the fuel. Admission of fuel should be directed to obtain complete combustion without the flame impinging on the roof bath or ports at the opposite ends.

Another function of the ports is to carry away the waste gases, and not allow the particles of dust, slag and ore in the gases to seek lodgement in them, instead of their being carried through to the slag pockets.

In a basic furnace the melter keeps careful watch to keep the port angles, or breasts patched and daubed with chrome ore or magnesite to keep them up through the duration of the campaign of the furnace bottom.

In working a "heat" the melter takes samples of the metal by dipping a spoon into the bath and pouring the metal thus obtained, into a nearby "test ingot" mould. After water quenching the ingot is broken in two. The melter, on inspection of the fracture, can estimate the carbon within 0.02 to 0.03% in a steel whose carbon is under 0.25%. The modern laboratory is equipped with methods of rapid determination, so that in a few minutes the melter's visual inspection can be checked by the analysis, in time to correct his bath if necessary. The first sample is taken after the lime comes up, in basic practice.

In the control of the fuel and door operation, the melter has a responsibility not often appreciated. The amount of air drawn in through the doors may modify largely the air delivery to the furnace. In a well operated furnace, the velocity of inflow should carry the air and gas to the center of the furnace. From that point, the draught of the stack should pull the gases through the furnace and regenerators. The condition in the furnace laboratory should be one of perfect equilibrium with the atmospheric pressure, so that on opening a door there should be neither inflow of air nor outflow of gas. In this way the proper amount of air delivered through the ports is not increased undesignedly.

Should the flame be permitted to impinge on a portion of the brickwork, the heat is deflected at an angle equal to the angle of incidence, quite the same in action as is the case with light. Thus a hot spot on a breast wall may cause a hot spot on a port on the roof and cause a melting down and destruction of the port or roof. In watching the flame action, the melter is not only able to economize fuel but lengthen the "campaign" of his furnace.

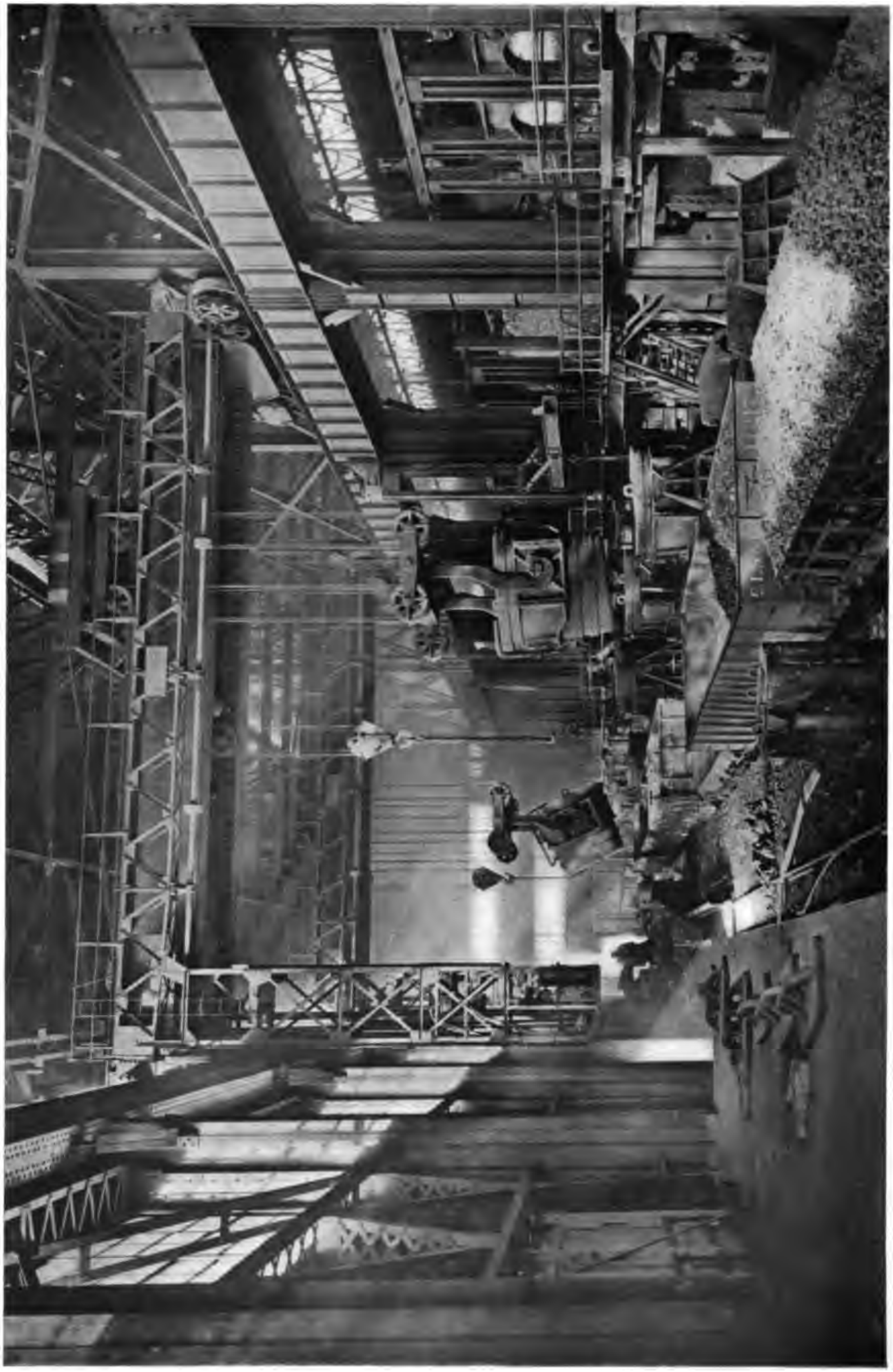


Figure 26—INTERIOR OF A LARGE STEEL MILL

In this view the casting side of a large steel plant is shown. The furnaces, the jib cranes for handling the spouts, the ladles, the overhead cranes and the casting on cars equipment may be seen.

CHAPTER X

Electric, Open Hearth and Bessemer Steel Temperature Measurements

F. E. Bash, A. I. M. & M. E. Soc., Sept. 1919

Whenever electric and open hearth steel men discuss the relative advantages of their respective methods, the question of temperature is always discussed, so that this discussion is written in the hope that definite data may settle some of the questions and encourage further investigations along these lines. The writer has had the opportunity of taking the tapping temperatures of steel from electric furnaces of different sizes in various plants and from a number of open hearths handling the same kind of steel. All temperature measurements were made with the same disappearing-filament type optical pyrometer and the corrections for emissivity applied were those worked out by Burgess which are 0.40 for steel streams and 0.65 for slag. The correction is applied by calculating the curve giving the relation between the true and apparent temperature in the following formula:

$$\text{Log } E = \frac{C_2 \log \varepsilon}{\lambda} \left\{ \frac{1}{T_2} - \frac{1}{T_1} \right\}$$

in which E = emissivity; $C_2 = 14{,}500$; ε = base of Napierian logarithms; wave-length of light used $= 0.65\mu$; T_2 = true temperature, in degrees absolute; T_1 = apparent temperature, in degrees absolute.

The curve showing the relation between true and apparent temperature for steel and slag are given in Fig. 27.

For the purpose of comparison of open hearth and electric furnaces, there are given in Table No. 28 the tapping temperatures of two 25-ton Heroult electric furnaces and one 6-ton, with one 50-ton acid, one 40-ton basic, and one 65-ton acid open hearth furnace, all making nickel ordnance steel for guns. The two 25-ton Heroult electric furnaces were finishing steel refined by the triplex process and the 6-ton Heroult finished steel that was partly refined in an open hearth. In this table, the tapping temperature and the temperature of the steel stream into the first ingot mould are given together with the mean of each column. The values for each plant are the average for a number of heats.

The table shows how closely the temperatures agree from plant to plant and in the

Table No. 28

Tapping Temperatures of Steel

Steel Co.	Tapping Temp. Deg. F.	First Ingot Deg. F.	Type of Furnace
A..................	2867	2744	25-ton Heroult Electric
B..................	2821	2745	6-ton Heroult Electric
B..................	2821	2721	6-ton Heroult Electric
C..................	2842	2768	50-ton open hearth, acid
D..................	2877	2753	40-ton open hearth, basic
C..................	2895	2794	65-ton open hearth, acid
Mean..............	2854	2754	
Mean for electric furnaces.............	2836	2737	
Mean for open hearth furnaces...........	2871	2772	

different types of furnaces. The greatest variation in tapping temperatures, between B and C, is only 74 degrees F. (24 degrees C.) while the average for all the electric furnaces is 35 degrees F. lower than for the open hearths, although it is generally thought that open hearth steel is tapped colder than electric.

The drop in temperature from the tap to the first ingot depends on the length of time the steel is held in the ladle, the size of nozzle, size and preliminary temperature of the ladle, and various other factors. It is interesting to note, however, that the mean drop in temperature of the steel from tapping to first ingot for both the electric and the open hearth furnace is 100 degrees F.

In Table No. 29 is given a tabulation of temperature data taken on two electric furnaces making nickel ordnance steel. At the time these temperatures were taken, the ingots were box poured so that temperature observations were made on the stream above and below the box on the first ingot and below the box on all subsequent ingots. Since there was no satisfactory method of taking temperature of the steel in the furnace, a chill test was made by taking out a small spoon of steel and noting the time required for a crust to form over the surface of the metal therein. These time values are also given.

It will be noted that the tapping temperatures vary from 2805 degrees to 2917 degrees, F. (1540 to 1603 degrees C.) but that most of them are within + or − 30 degrees F. of the mean. It will also be noted that the temperature of the steel stream into the second ingot mould is a little higher, on an average, than that into the first ingot mould. The reason for this is obvious as the metal lying next to the bottom of the ladle is colder than the main mass of the molten steel. Similar variations will be noted in taking measurements on the tapping stream from a furnace, as the metal in different parts of the hearth often varies 25 degrees to 30 degrees F. in temperature.

In an effort to find the relation between the tapping temperature of the steel and the time of the chill test, the respective values were plotted on a curve sheet with the result shown in Fig. 28. The curve is anything but a smooth one and shows how unreliable the chill-test method of judging temperatures is. In spite of all care in attempting to draw out the spoon in the same manner each time, the atmospheric conditions, room temperature, and other variables have an influence on the time required for the crust to form.

In Table No. 30 are given some temperatures taken on manganese and manganese hel-

Table No. 29

Summary of Temperatures for Nickel Gun Steel

First Ingot

Heat No.	Tap Temperature Degrees F.	Over Box Degrees F.	Under Box Degrees F.	Second Ingot Degrees F.	Third Ingot Degrees F.	Chill Test Seconds	Time Held in Ladle, Minutes
3 x 707	2895	2793	2737	2722	2705		8
3 x 710	2880	2842	2790	2797	2770	26	5½
3 x 711	2850	2761	2730	2747	2761	37	5
3 x 715	2917	2843	2768			40	8
3 x 719	2830	2805	2737			31	6
3 x 723	2805	2745	2720	2680		35	5½
4 x 651	2872		2761	2752	2728	38	7
4 x 666	2872	2813	2768	2730		27	5
3 x 727	2835	2775	2705	2680	2697	?	7
2 x 3146	2910		2730	2730	2730		
Mean......	2867	2797	2744	2732	2736	33.5	6.5

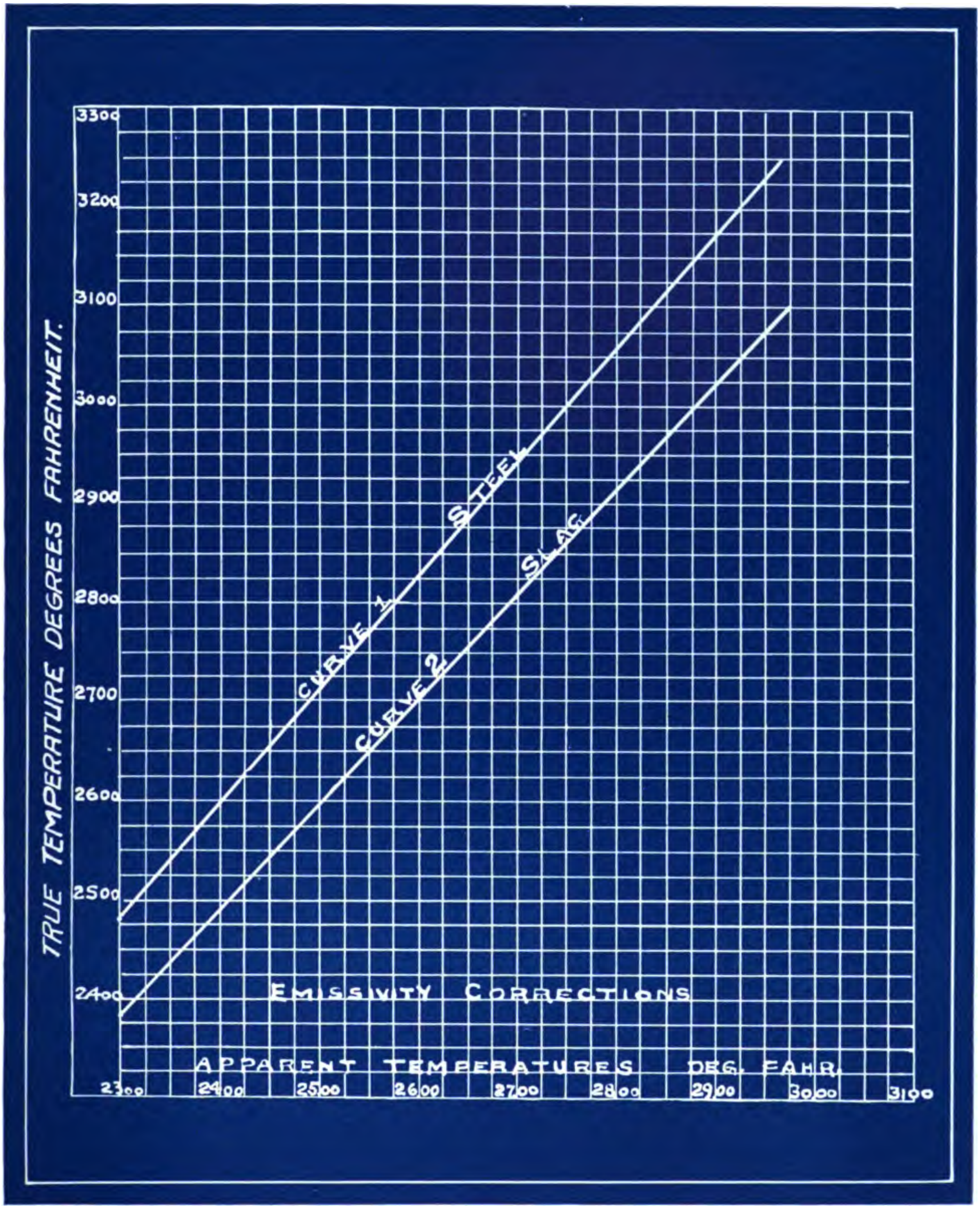


Figure 27—EMISSIVITY CORRECTIONS

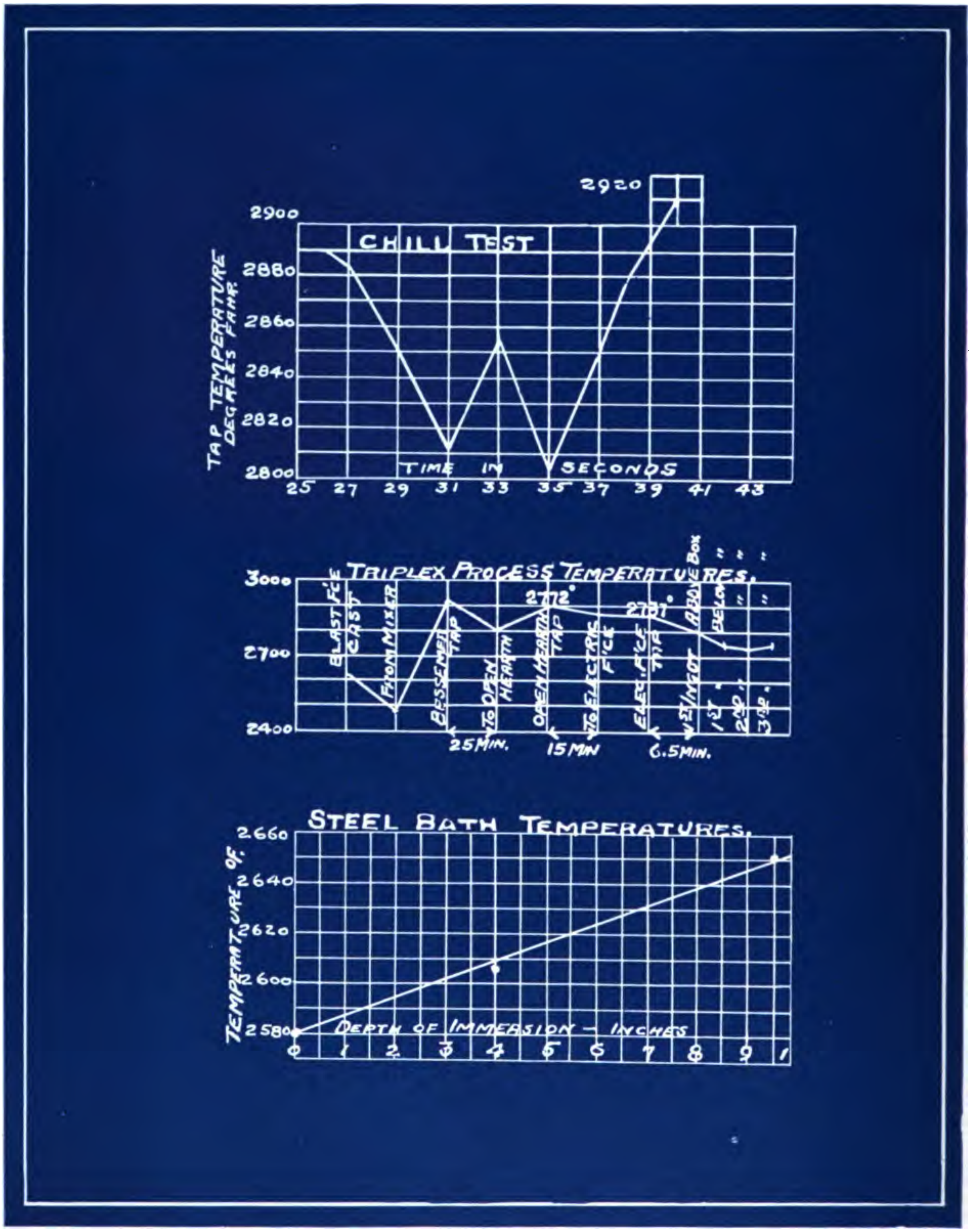


Figure 28
Curves showing relation between tapping temperatures of Steel and time of Chill Test; Triplex Process Temperatures and Steel Bath Temperatures.

met steel. The observations in this case were difficult to make for the reason that heavy clouds of smoke were given off from the manganese so that the readings had to be made from the windward side and a moment chosen for making the reading when the stream was unobscured. The manganese was melted in a 15-ton Heroult furnace and tapped into a ladle which was then transferred to the open hearth plant where the manganese was poured into the steel ladle at the time that the steel was tapped.

Table No. 30

Manganese Steel Temperature

Time P. M.	Temp. Deg. F.	Remarks
6:04	2790	Tap manganese from 15-ton Heroult furnace.
6:30	2822	Tap open hearth furnace.
6:32	2549	Pour manganese in steel ladle.
6:34	2840	Tap open hearth furnace.
6:44	2605	First ingot manganese steel.
6:45	2605	Second ingot manganese steel.
6:47	2647	Third ingot manganese steel.

An opportunity was presented to take temperatures on steel made by the triplex process, so at the same time blast furnace tapping temperatures were taken and a record made from the blast furnace to the steel ingot. The practice was to take the molten pig iron to a mixer from which it went to a Bessemer converter, thence to an open hearth furnace, and finally to an electric furnace for finishing. The mean of readings taken on each operation are set down in Table No. 31. The value for the Bessemer tap is the mean for 10 heats and that for the electric furnace is for 11 heats.

In Fig. 28, the data for this table is presented graphically. The great increase in temperature in the Bessemer converter and other temperature relations are distinctly brought out.

In Table No. 32 is given data on tapping and teeming for three open hearth furnaces in different plants making nickel ordnance steel and one making shell steel.

Six 26-inch octagon ingots were poured with large end up, each ingot was individually bottom poured from the 40-ton basic open hearth furnace. One 63-inch octagon was poured from two 65-ton open hearth furnaces that were tapped simultaneously and poured consecutively.

Beside the temperature measurements on nickel ordnance steel, a number of readings were made on different types of steel in two 10-ton Ludlum electric furnaces. These were taken through the courtesy of A. E. Armstrong, V. P. of the Ludlum Steel Co. The practice was to refine with two or three slags so that it was possible to take readings on the oxidized surface of the molten steel during the skimming and also to get readings on thin slag patches on the metal. It was found that readings on slag patches corrected for an emissivity of 0.65 almost exactly agreed with uncorrected readings on the iron oxide adjacent. In other words, if the radiation from the oxide in the furnace with the arc off and the door open is that of a black body, then the emissivity of slag is approximately 0.65, as stated by Burgess. In Table No. 33

Table No. 31

Mean Temperatures from Blast Furnace to Finished Steel

	Temp. Deg. F.	Remarks
1	2625	Mean of metal streams into ladles from blast furnace.
2	2485	Mixer metal charged into Bessemer.
3	2909	Bessemer Tap.
4	2797	Charge Bessemer steel to open hearth furnace.
5	2902	Tap open hearth furnace.
6	2872	Charge electric furnace.
7	2867	Mean electric furnace tap.
8	2797	First ingot pour above box.
9	2744	First ingot pour under box.
10	2732	Second ingot pour under box.
11	2736	Third ingot pour under box.
	Temp. Deg. F.	Temperature Differences
1	100	Temperature drop from Bessemer tap to open hearth charge.
2	25	Temperature drop from open hearth tap to electric furnace charge.
3	70	Temperature drop from tap of electric furnace to stream from ladle for first ingot for average of 6½ min. in ladle.
4	55	Temperature drop through box.

are given a number of readings on different skims made in this manner. It will be noted that the mean values for the two columns agree exactly with each other. If the emissivity of slag is 0.65, then the iron oxide under the above conditions must give black body radiation for red light.

In Table No. 34 is given a summary of data taken on tapping and teeming a number of heats. The steel was tapped or poured from the furnace into two ladles and then very quickly teemed into ingot moulds.

In order to make sure of the steel temperature in the furnace, a Dixon graphite tube 4 feet (1.2 m.) long by 4 inches (10 cm.) outside diameter with a closed end, was pushed into the steel and held there until the end had come to temperature, at which time a reading was made with the optical pyrometer sighted down the axis on the inside of the closed end, which was in the steel. Under these conditions, the reading in the tube should give the true temperature of the steel. One such reading was taken just before a tap and is recorded in the table. It is only 17 degrees F. below the temperature read on the steel stream, which is a very good agreement. Readings made on the slag surface in the furnace before the tap do not agree so well with readings on the stream, as is also shown.

Table No. 32

Open Hearth Steel Temperatures on Nickel Ordnance Steel

Time	Temp. Deg. F.	Remarks
		50-ton Acid Open Hearth Furnace
11:55	2842	Tap Steel.
		Held 10 min. in ladle.
		Four ingots bottom poured in sets of two
12:12	2768	Pour first two ingots.
12:19	2768	Pour second two ingots.
		40-ton Basic Open Hearth Furnace
4:10	2877	Tap steel.
4:21	2713	First ingot.
4:22	2722	Tong hold.
	2753	Second ingot.
	2722	Second ingot.
	2722	Third ingot.
	2705	Third ingot.
	2713	Fourth ingot.
		65-ton Acid Open Hearth Furnace
8:33	2895	Tap one furnace. Other tap not recorded.
8:43	2835	Stream from ladle to runner.
8:44	2843	Stream from ladle to runner.
8:47	2768	Stream into headbox.
8:47½	2737	Stream into headbox.
8:48	2688	Stream from headbox.
8:51	2761	Stream into headbox.
8:56	2761	Stream into headbox.
		Second ladle.
9:00	2753	Stream into headbox.
9:01	2761	Stream into headbox.
9:04	2761	Stream into headbox.
9:06	2745	Stream into headbox.
9:09	2737	Stream into headbox.
9:12	2768	Stream into headbox.
9:20	2745	Stream for four 23-in. octagons.
9:21	2620	Steel rising in mould one-third full. Light smoke.
9:22	2782	Stream to group of 23-inch octagons.
9:25	2813	Stream to group of 23-inch octagons.
9:29	2828	Stream to group of 23-inch octagons.
9:30	2745	Stream to group, dark streak, good.
		65-ton Acid Open Hearth Furnace Nickel Chromium Steel
9:37	2879	Tap steel.
	2895	Tap steel.
	2910	Tap steel.
		Teem.
9:44	2835	First group (8 tons to a group, four ingots)
9:45	2828	First group.
9:49	2835	Second group.
9:55	2790	Fifth group.
10:01	2775	Sixth group.
10:03	2735	Seventh group.

Note: Acid furnace on shells, 3-in. nozzle; carbon 0.60; chromium 2.25; nickel 3.5.

Table No. 33

Summary of Data on Slag Skimming

Optical Reading on Slag Patch Degrees F.	Optical Reading on Iron Oxide Degrees F.	Remarks
2611	2618	H. S.
2621	2629	XIC.
2611	2618	C. S.
2718	2709	C. S.—refractory slag.
2628	2618	C. S.
2532	2562	C. S.—cold.
2728	2694	C. S.—same heated.
Mean 2636	2636	C. S.

Further readings in a graphite tube were made at another time. The arc had been off for about 10 minutes and the door was opened just sufficiently to allow the tube to be inserted. A reading was made on the thin slag surface beside the tube and then the tube at two different depths, which

Table No. 34

Ladle Temperatures

	Temperature in Furnace Degrees F.	Reading on Steel Tapping Corrected Degrees F.	Reading on Slag Tapping Corrected Degrees F.	First Ingot Degrees F.	Last Ingot Degrees F.	Remarks
Arc Off, Slag	2815	2797	2792	2746	2640	First ladle —C. S.
			2770	2746	2625	Second ladle—C. S.
		2737		2700	2625	First ladle —XIC
		2686	2652	2670	2597	Second ladle—XIC
Arc Off, Slag	2789	2730	2711	2653	2580	First ladle —C. S.
		2686	2675	2617	2550	Second ladle—C. S.
Tube	2673	2690		2650		First ladle —C. S.
		2633	2646			Second ladle—C. S.
		2716		2677	2597	First ladle —XIC
		2677		2637	2620	Second ladle—XIC
		2790		2723	2662	First ladle —H. S.
		2759	2751	2651	2661	Second ladle—H. S.
Arc (Slag) on	2946	2745		2732	2699	First ladle —XIC
		2717		2692	2611	Second ladle—XIC

	Degrees F.
Mean drop from tapping temperature to first ingot (max. 108°, min. 13°)	36
Mean drop from first to last ingot, for 5-ton ladle	62
Mean temperatures for first ladle tap	2743
Mean temperature for second ladle tap	2704
Mean difference between first and second ladles	39

were calculated from measurements of depth of immersion of the tube. The readings are given in Table No. 35 and are plotted in Fig. 28; they show the temperature gradient of the steel bath from the surface to a 9-inch (23 cm.) depth. The top was cooler due to the fact that the arc had been off for a few minutes. This also seems to show that a reading made on a thin slag surface in a furnace that is enclosed, with the arc off, gives true temperatures.

At this point the writer wishes to state that the steel poured from these electric furnaces was the coldest of any he has had occasion to take temperatures on, either open hearth or electric and further contradicts any supposition that electric steel is hotter than open hearth, at least when it is tapped, although it may be hotter during the refining period.

In Tables Nos. 36 and 37, temperatures are given for tapping and teeming a 30-ton basic Heroult furnace. The steel was used for castings and for that reason had to be hotter than steel for large ingots. The temperatures given in Table No. 37 for tapping manganese steel are the hottest of any electric steel the writer has had occasion to make measurements on. However, it is not hotter than open hearth steel for castings or Bessemer steel for the same purpose, as may be seen by examination of Table No. 38.

In Tables Nos. 36 and 37 it will be noted that there is some fluctuation in the teeming temperatures. This is due to the fact that the steel was poured over the tip of the ladle and was sometimes large and sometimes small. The small stream cooled much more rapidly and as a consequence a lower temperature was read.

Table No. 35

Slag Temperatures

Temp. Read Degrees F.	Remarks
2580	On slag surface, arc off 10 min.
2606	In closed-end tube, immersed 4 in.
2650	In closed-end tube, immersed 4 in.
2629	Slag surface, arc off.
2618	Tube in slag.

Table No. 36

Carbon Steel for Castings

Time from Start of Tap Min.	Sec.	Temp. Deg. F.	Remarks
	17	2960	On slag tapping.
	28	2920	On slag tapping.
	46	2982	On slag tapping.
	64	2952	On slag finish tapping.
2	30	....	Started to skim.
3	45	....	Finished skimming.
4	45	....	Finished weighing.
5	22	2887	First shank.
7	30	2865	Second shank.
8	20	2821	Poured second shank into small mould.
9	13	2835	Third shank.
9	53	2797	Pouring third shank into mould.
10	9	2797	Pouring third shank into mould.
10	46	2828	Fourth shank.
11	5	2782	Pouring fourth shank into mould.
11	43	2775	Pouring fourth shank into mould.
12	10	2835	Fifth shank.
12	35	2761	Pouring fifth shank.
13	59	2775	Pouring from ladle into first mould.
14	41	2730	Pouring from ladle into second mould.
15	15	2688	Third mould, small stream.
16	3	2782	Fourth mould, large stream.
16	21	2768	Fourth mould.
16	41	2761	Fourth mould.
16	52	2753	Fourth mould.
17	12	2761	Fourth mould, oxidized stream.
20	3	2797	Sixth mould, oxidized stream.
21	2	2745	Seventh mould.

Table No. 37

Manganese Steel for Castings

Time from Start of Tap Min.	Sec.	Temp. Deg. F.	Remarks
	15	3053	Steel stream.
	34	3025	Steel stream.
	52	3025	Steel stream.
1	14	3037	Steel stream.
1	38	3025	Steel stream.

Table No. 38

Temperature Observations on 3-Ton Acid Bessemer Converter

Time 2:07		Temp. Deg. F.	Remarks
		2433	Charging Bessemer on stream
Time after Start of Blow Min.	Sec.		
2	50	2574	Flame from Bessemer.
3	10	2632	Flame from Bessemer.
3	37	2722	Flame from Bessemer.
4	10	2824	Flame from Bessemer.
5	12	2860	Flame from Bessemer.
6	43	2747	Flame from Bessemer.
7	18	2752	Flame from Bessemer.
8	0	2527	Ferro-manganese into ladle.
9	32	3060	Tap Bessemer.
11	53		Finish Tap.

CHAPTER XI

Casting and Stripping

During the melting and refining periods, the melter and his helpers have ample time to watch the heat, tend to the regenerator reversals, look after the minor duties and also prepare all tools and materials for the cast. There are from four to eight hours in which to take care of these matters, while the cast occupies not over fifteen minutes.

Preparations for the cast require the making ready of the ladle stopper rigging. The slag pots must be placed ready for the "run off" slag. Spouts must be made up and inspected and the spout crane in working order. Ladle recarburizers and other additions weighed should be placed for instant shoveling into the ladle. The ladle itself must be heated and accessible. Quick and intensive work of the cast requires the prior placing of all hand tools, bars and appliances, clay and loam, within reach for immediate use.

Steel ladles range in capacity from the smallest up to 100 tons of steel and call for 150 to 175-ton traveling cranes to handle them. The manipulation of these great cranes and heavy loads is so expertly done that in the case of a "running" stopper, moulds can be accurately filled, by jumping the line of ingot moulds and accurately hitting the top hole in the next empty mould with the stream of metal.

The runner on the pouring side of the furnace is detachable from the furnace and is handled by a jib crane. This crane is used for cleaning up "messes" made up of slopped over metal, slag and debris which accumulate. These accumulations are broken up by engaging the crane hook with chains, bars or billets (which were previously placed on the floor so that they became embedded in the spillings), and pulling the mass out.

An auxiliary ladle, ready for use, is always kept close at hand in case of trouble or a cast too great for the first ladle is drawn.

The ladle stopper must be rebricked and dried between casts, all ladles cleaned of skulls, patched and reheated. Each cast results in the consumption of refractories for the ladles. A twenty-ton heat uses one nozzle brick, eight sleeve brick and one stopper brick; another heat, fifty ladle brick, one stopper, one nozzle and twelve sleeve brick.

Casting pits, whether for foundries or for corrugated or large ingots should be kept clean and perfectly dry; otherwise a spill of metal will result in a dangerous explosion.

Much investigation remains yet to be done to determine the effect of the size of the metal stream in pouring. The size of the nozzle opening and effect of secondary pouring into an ingot mould are not yet satisfactorily settled.

Ordinarily, iron moulds have a life of about 60 heats and stools 700 heats, while steel moulds last as high as 500 heats. Some experimental work has been done regarding the rapidity of cooling in sand moulds as compared with iron moulds, in the hope of quickening the cooling of ingots. Water cooled moulds have been tried in England, but are not now used. In the ordinary ingot

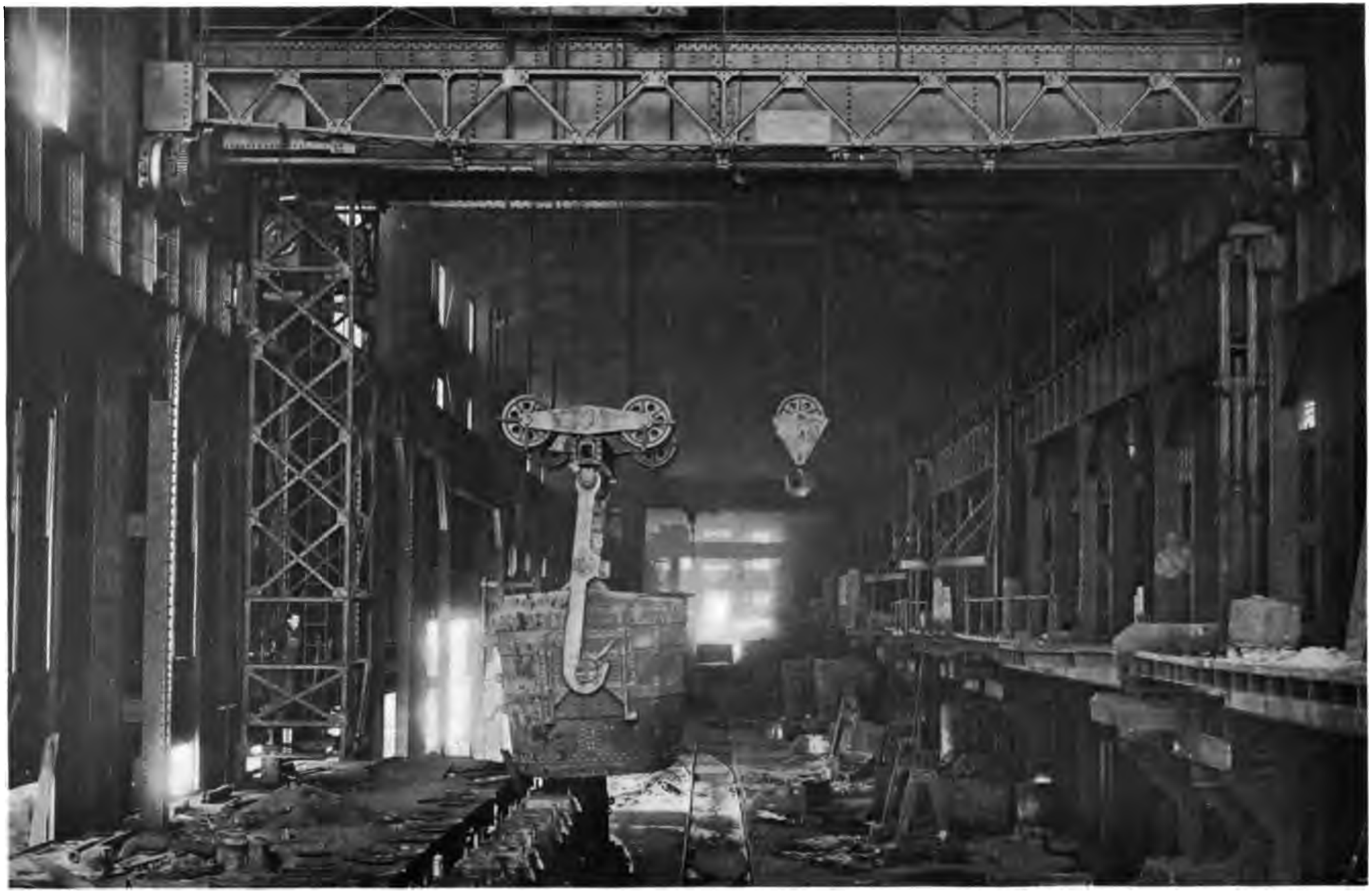


Figure 29—CASTING SIDE INTERIOR OF A LARGE STEEL MILL

This view shows a 90-ton ladle crane installed at the Sharon Works of the Carnegie Steel Company. The position of the craneman assists in rapid working as he is in position to watch all operations.

mould, the corners of the ingot harden first and the center of the face later. This produces a tendency to form surface cracks. To a large degree, this has been overcome by the use of corrugated moulds in which the surface is divided by the corrugation in small sections, thereby eliminating this tendency.

The indications are that using sand moulds the rate of ingot cooling is 125° per inch per minute, while for iron moulds the figure is 400°. The moulds heat up as the ingot cools and the mass of metal in each have a marked influence on the time of cooling.

Without going into a discussion as to causes and results of segregation of metalloids in an ingot, it may be well to state that the larger the ingot the greater the segregation. Carbon, phosphorus and sulphur segregate from the steel in the order named as to quantity, carbon leading in amount.

In foundry work, practice is quite different on the casting floor from ingot casting. In a general way, procedure is slower on account of moulding, slower pouring, and the necessity of permitting castings to completely harden and cool off before stripping to temperatures far below the stripping temperature of ingots. The metal not appearing as net castings, but used as risers and gates corresponds in quantity to the crop ends of defective steel found in ingot casting and rolling. It is to be hoped that at some future time the expense incident to these items may be reduced.

Closely associated with this subject of casting is that of stripping. The function of a steel mill is summed up in the work of producing a maximum weight of chemically and physically satisfactory and sound stripped ingots and castings. All other items of steel such as steel in "messes," bled ingots, stuck ingots, butts, etc., are sources of expense to add to the cost of the acceptable net output. Therefore the attention of the superintendent should be given to this part of a steel works with as searching care as the working of his furnaces.

As the fluidity of high carbon steel is greater than that of a lower carbon steel, a lower casting temperature is permissible with a high carbon content, without increasing the waste metal. As another way of expressing it, with equal temperatures high carbon steel gives a larger proportion than low carbon steel of sound ingots or castings. This is indicated by the figures given below of the relative carbon ingot weights and temperature.

Table No. 39

Ingots Weights and Temperatures

Carbon in Steel %	Weight of 18" x 22" x 70" ingot Lbs.	Solidifying Temperature Deg. F.
0.08 to 0.12	6050	2685
0.15 to 0.30	6100	2675
0.30 to 0.50	6150	2650
0.50 to 0.70	6250	2615
0.70 to 0.90	6350	2585
0.90 to 1.10	6400	2650

Ingot stripping is now done by heavy machines which lift the ingot mould from the casting car and then force the ingot down onto the car by a plunger operated either with electric or hydraulic power. The ingot mould is then lifted clear and placed on another car ready for use again. The lifting capacity of these machines runs up to 25 tons, while the ram can exert a pressure up to 250 tons on the ingot. In some cases of "stuck" ingots, the force used approaches the maximum power available.

Three types of strippers are used, as follows:

1. Those housed in the open hearth building itself. The overhead traveling crane type is used here.
2. Electrically operated, built on a separate crane runway.
3. Combined stripping and soaking pit charging cranes.

The former style of hydraulic operated stripper has given way to electrical operation. It is good practice to have an auxiliary

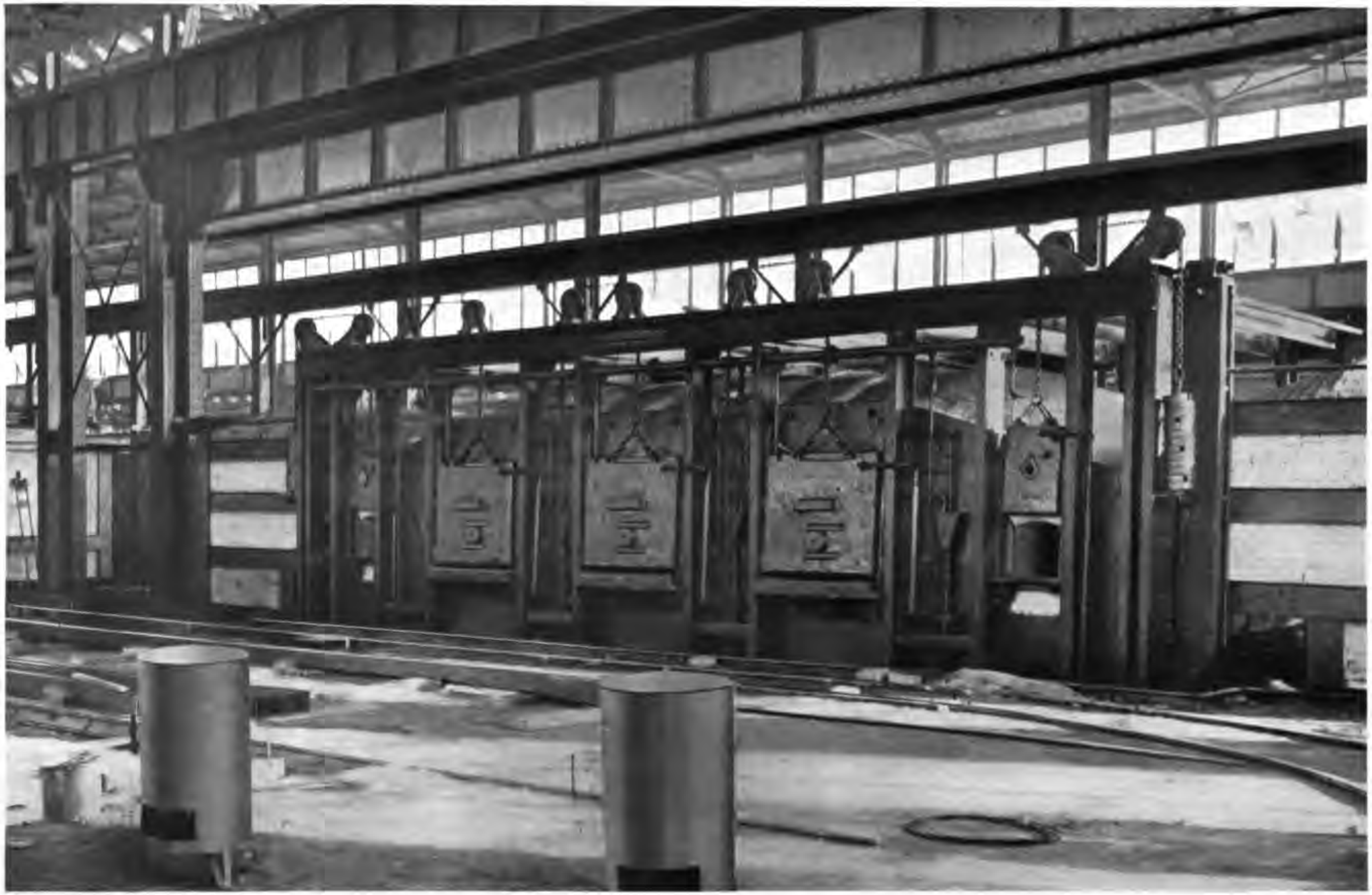


Figure 30—35-TON ACID STATIONARY WELLMAN FURNACES

The charging side of one of two furnaces installed in the U. S. Army Arsenal, Watertown, Mass. These furnaces were used during the war for heavy gun forging castings and other ordnance work.

hydraulic stand of great power to remove persistent stickers. Usually an ingot cooled in the mould will strip easily, but even when cold some ingots are difficult to strip.

The time involved in handling a heat is approximately as follows:

Table No. 40

Time of Handling a Heat

Furnace work—Charging, melting, refining, patching	4–9 hours
Tapping the steel	15 minutes
Casting 28 standard ingots	15 minutes
Transferring ingot train to stripper	10 minutes
Stripping	30 minutes

Thus close on to one hour and a quarter is used in passing the steel through the open hearth department after it has left the furnace.

It has been found that the placing of strippers out of doors is not advisable. The reason is that the filled moulds and stripped ingots cool off too rapidly and unevenly because of being exposed to wind, rain and snow. The result is an aggravation of minor defects on the ingot surface. These defects would not have been injurious to the rolled product made from the ingots if the ingots had been more slowly cooled in a protected position.

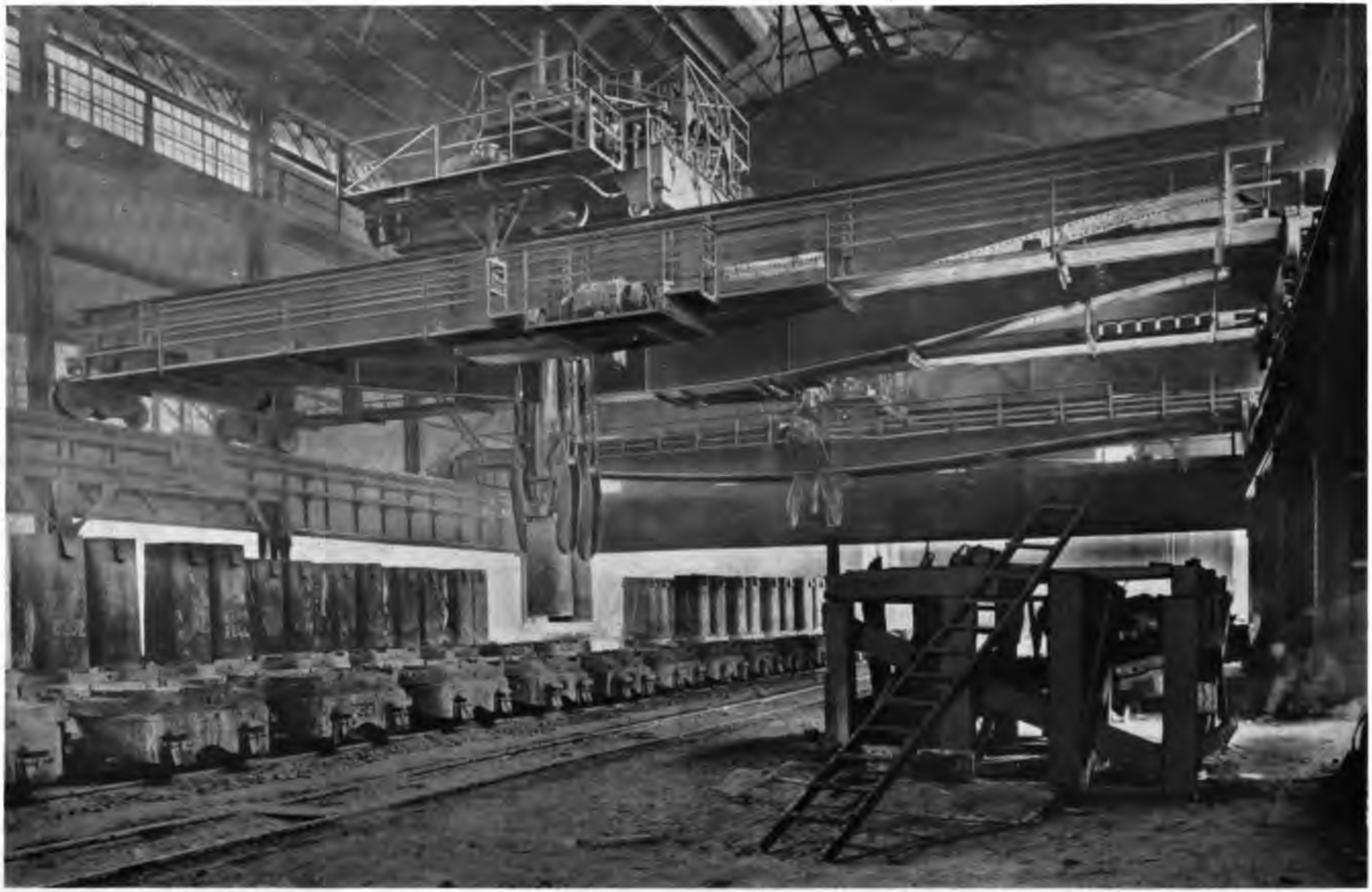


Figure 31—400-TON DUPLEX SCREW TYPE INGOT STRIPPER

Installed at the Youngstown Sheet & Tube Co., by the Morgan Engineering Co. The trolley has two separate and independent stripping mechanisms, each of 200-ton capacity, which may be operated independently or together.

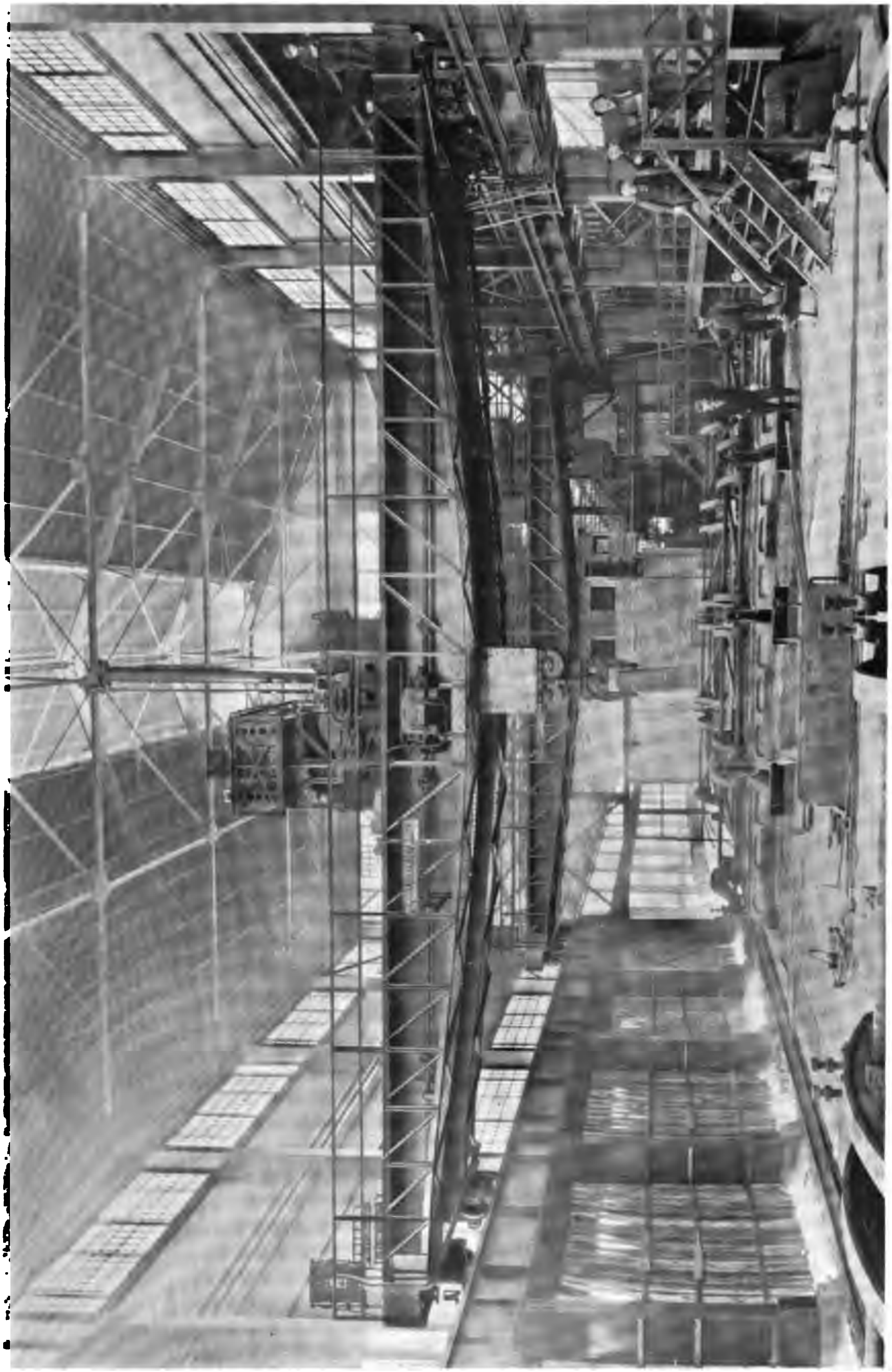


Figure 32—5-TON VERTICAL CHARGER

Installed at the Brier Hill Steel Company, Youngstown, Ohio, by the Morgan Engineering Company, Alliance, Ohio. The trolley is provided with a 5-ton auxiliary hoist. All motions are motor operated.

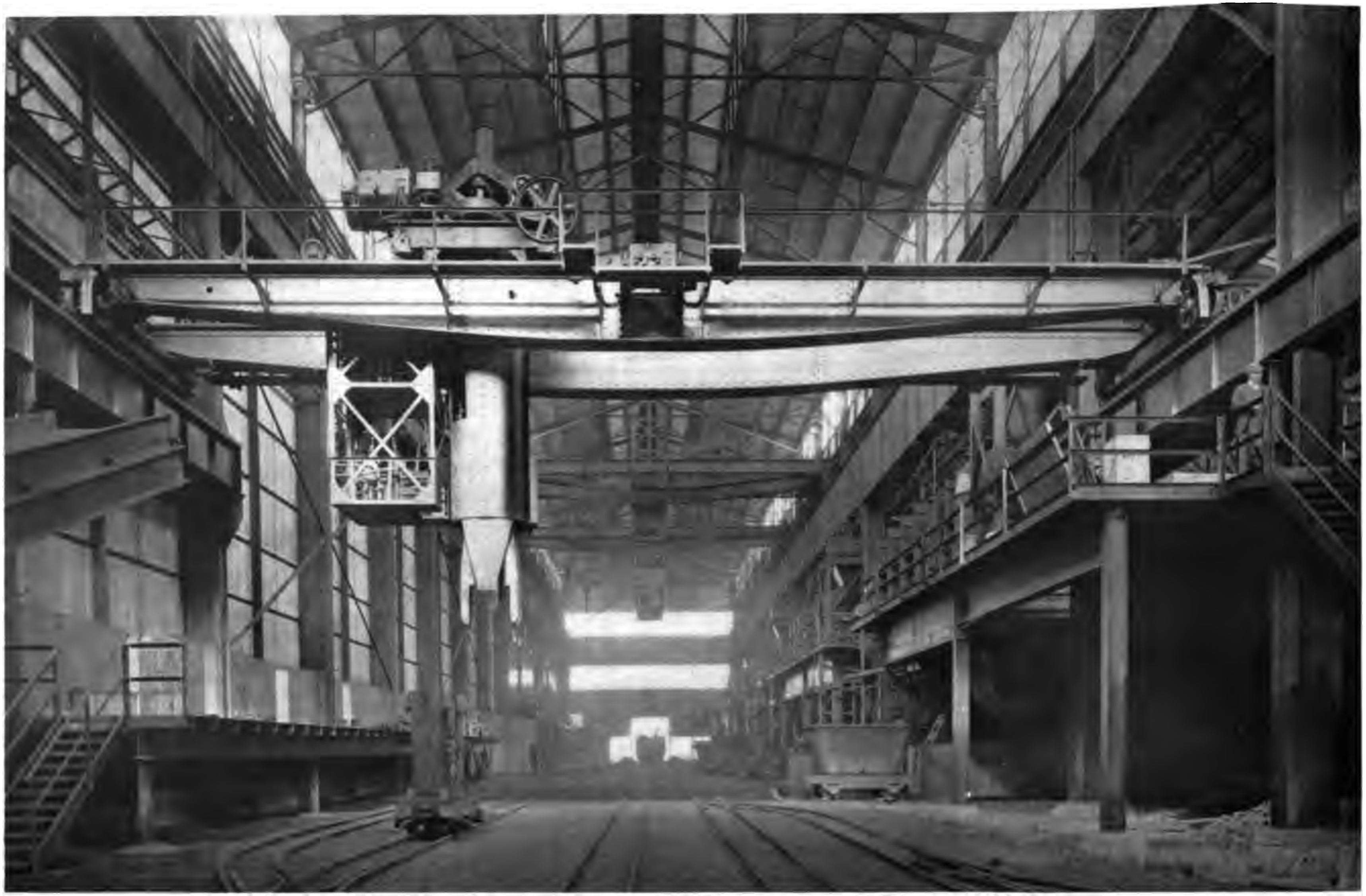


Figure 33—100-TON SCREW TYPE INGOT STRIPPER

Installed at Bethlehem Steel Co., Lebanon, Pa., by the Morgan Engineering Co. This type of stripper has the same amount of power to pull the "bull nose" out of a soft ingot as it has in pushing the ingot out of the mold.

CHAPTER XII

Proportioning the Charge

The proportions of the constituents of a charge of raw materials depend upon the silicon content of the pig metal, and the quality and quantity of the steel scrap. Should a very low silicon iron be available no scrap need be used. But a certain amount of pig iron must be melted to prevent great loss from oxidation of the comparatively pure scrap.

A high silicon pig with little scrap would make so heavy a layer of slag over the bath that the working of the heat would be quite difficult. A large proportion of scrap and little pig metal would yield so little slag that the metal would be rapidly oxidized, and the product would be so low in silicon, manganese and carbon as to be unsatisfactory and hard to work.

Assuming the sulphur and phosphorus to be within allowable limits, in an acid furnace, the charge must be made up with reference to the oxidation of carbon, silicon and manganese. To oxidize one part of carbon, there must be 1.33 parts by weight of oxygen. Reciprocally one part by weight of oxygen will oxidize 0.75 parts of carbon, or 0.875 parts of silicon or 3.438 parts of manganese. Therefore one part of silicon = $\frac{1.143}{1.333}$ = 0.857 part carbon and one part manganese = $\frac{0.291}{1.333}$ = 0.218 parts carbon.

In calculating the charge, consider metal composed as follows:

	Pig	Scrap
Carbon	3.5%	0.34%
Silicon	2.0%	0.01%
Manganese	0.7%	0.25%

Reducing the silicon and manganese to a carbon equivalent, there are:

Pig Iron—
3.5% Carbon = 3.500% Carbon
2.0% Silicon x 0.857 = 1.714% "
0.7% Manganese x 0.218
= 0.153% "
Total 5.367% "

Scrap—
0.34% Carbon = 0.34 % Carbon
.01% Silicon x 0.857 = 0.009% "
.25% Manganese x 0.218
= 0.054% "
Total 0.403% "

That is the pig is equivalent to an iron of 5.367% carbon and no silicon or manganese while the scrap is similarly equal to a steel of 0.403% carbon.

Then using hundred parts or percent
Let x = number of parts of pig
100-x = number of parts of scrap
and we have
5.367 x = total carbon equivalent of metalloids in the iron.
0.403 (100-x) = total carbon equivalent of metalloids in the scrap.
5.367 x 0.403 (100-x) = 100.0
x = 12.0% pig
100-x = 88.0% scrap.

The additions of ferrosilicon and ferromanganese to be made are calculated from the following data:

Type of furnace........................Acid open hearth
Weight of steel required.................... 40,000 pounds

	C. %	Mn. %	Si. %	S. %	P. %	Fe. %
Pig iron charged	3.50	0.70	2.0	0.04	0.08	93.68
Steel scrap charged	.34	.25	.01	.04	0.04	99.32

	C.	Mn.	Si.	S.	P.	Fe.
Ferrosilicon charged	1.50	2.00	15.00	.01	.04	81.45
Ferromanganese charged	6.00	60.0	.48	trace	.05	33.47
Steel before recarburizing	.20	.10	.01	0.04	.04	99.61
Steel final composition	.30	.75	.30	0.04	.04	98.57

	FeO	MnO	SiO_2	CaO
Slag	35.0%	17.0%	45.0%	3.0%

The proportion and equivalent of the charge having been found to be:

	%	Carbon Equivalence	Carbon in Charge
Pig iron....................	12.0	5.367%	258.0 lbs.
Scrap steel..................	88.0	.403%	142.0 lbs.
Total..................	100.0	1.00%	400.0 lbs.

The weights of the charge will be increased to allow for the oxidation of the carbon, silicon, manganese and iron lost in the slag, thus:

Allowing for decarburizing and oxidation of Mn, Si.

$$\left.\begin{array}{l}\text{Pig iron—}40{,}000 \text{ x } 12\% = 4{,}800.0\\ \quad \div (1.0 - 0.05367 = 0.94633)\\ \qquad = 5{,}070 \text{ lbs.}\\ \text{Scrap steel—}40{,}000 \text{ x } 88\% =\\ \quad 35{,}200.0 \div (1.0 - 0.00403 = 0.99597)\\ \qquad = 35{,}340 \text{ lbs.}\end{array}\right\} \begin{array}{c}40{,}410\\ \text{lbs.}\end{array}$$

Allowance for loss of iron which goes into the slag as FeO.

Manganese.

$$\left.\begin{array}{l}5{,}070 \text{ x } 0.007 = 35.5 \text{ lbs.}\\ 35{,}340 \text{ x } 0.0025 = 88.4 \text{ lbs.}\end{array}\right\} \begin{array}{c}123.9\\ \text{lbs.}\\ \text{Mn.}\end{array}$$

$$\left.MnO = 123.9 \text{ x } \frac{71 \text{ mol.wt.}MnO}{55 \text{ mol.wt.}Mn}\right\} \begin{array}{c}147.0\\ \text{lbs.}\\ MnO.\end{array}$$

Silicon.

$$\left.\begin{array}{l}5{,}070 \text{ x } 0.02 = 101.4 \text{ lbs.}\\ 35{,}340 \text{ x } 0.0001 = 0.4 \text{ lbs.}\end{array}\right\} \begin{array}{c}101.8\\ \text{lbs. Si.}\end{array}$$

$$\left.SiO_2 = 101.8 \text{ x } \frac{53 \text{ mol. wt. } SiO_2}{21 \text{ mol. wt. } Si}\right\} \begin{array}{c}257.0\\ \text{lbs.}\\ SiO_2\end{array}$$

According to the assumed analysis of the slag the MnO and SiO_2 are equal to 62% of the total slag, the weight of which will be (147.0+257.0) = 404.0 lbs. ÷ 62% = 651. lbs.

Iron in the FeO of the slag is 21% of the 35% of FeO.

651.0 x 35% x 21% = 50.0 lbs. of iron.

Corresponding pig iron = 50.0 ÷ 93.68% = 54 lbs., say 50 lbs.

Pig iron equivalent to manganese and silicon losses are already provided for in the 40,410 lbs. above.

The total charge thus far is 40,410 + 50 = 40,460 lbs.

Make up as follows:

$$\left.\begin{array}{l}\text{Pig iron } 5070 + 50 = 5{,}120 \text{ lbs.}\\ \text{Steel scrap } 35{,}340 \text{ lbs.}\end{array}\right\} \begin{array}{c}40{,}460\\ \text{lbs.}\end{array}$$

Weight of metalloids and manganese and iron in the steel.

Carbon	40,000 lbs. x 0.0030 =	120 lbs.
Manganese	40,000 lbs. x 0.0075 =	300 lbs.
Silicon	40,000 lbs. x 0.0030 =	120 lbs.
Sulphur	40,000 lbs. x 0.0004 =	16 lbs.
Phosphorus	40,000 lbs. x 0.0004 =	16 lbs.
Iron	40,000 lbs. x 0.9857 =	39428 lbs.
	40,000 lbs. x 1.000 =	40000 lbs.

Ferrosilicon.

There is a loss of silicon accompanying the use of ferrosilicon and an excess of 20% is made to overcome this.

Amount needed = 120 lbs. of silicon ÷ 15% = 800 lbs. — 15% ferrosilicon. 800 x 120% = 960 lbs. ferrosilicon required.

In the 960 lbs. are

Carbon	14.00 lbs.
Manganese	19.00 lbs.
Silicon	144.00 lbs.
Sulphur	.01 lb.
Phosphorus	.04 lb.
Iron	781.92 lbs.

Ferromanganese.

The percent of loss will not be so great, because but one-third of the ferro is added to the bath and the remainder is put into the ladle, using a 60% ferro.

Amount needed = 300 lbs. ÷ 60% = 500 lbs. ferromanganese.

The residual amount left in the bath before the additions are made are 40,000 x 0.001 = 40 lbs. This leaves a balance of 7 lbs., hence the loss is made up.

In the 500 lbs. are—

Carbon	30.00 lbs.
Manganese	300.00 lbs.
Silicon	2.40 lbs.

Sulphur	Trace
Phosphorus	0.2 lb.
Iron	167.4 lbs.

Carbon.

Residual in bath 40,000 x 0.002 = 80 lbs.
Ferrosilicon = 14 lbs.
Ferromanganese = 30 lbs.
Total 124 lbs.

Iron.

Residual in bath 40,000 x 98.57% =39428.0 lbs.
Ferrosilicon = 781.9 lbs.
Ferromanganese = 167.4 lbs.
Total 40377.3 lbs.
Deduct loss in slag 50.0 lbs.
Net iron 40327.3 lbs.

Manganese.

Residual in bath 40,000 x 0.001 = 40 lbs.
Ferrosilicon 19 lbs. x 0.80 = 15 lbs.
Ferromanganese 300 lbs. x 0.80+7 lbs. =247 lbs.
302 lbs.

Silicon.

Residual in bath 40,000 x 0.001 = 40.0 lbs.
Ferrosilicon 960 lbs. x 15% x 80% (20% loss) =115.2 lbs.
Ferromanganese 500 lbs. x 0.0048 = 2.4 lbs.
Total 157.6 lbs.

Sulphur.

No appreciable change in weight.
40,000 x 0.04 = 16.0 lbs.

Phosphorus.

In bath 40,000 x 0.04% = 16.0 lbs.
Ferrosilicon 960 x 0.04% = 0.4 lbs.
Ferromanganese 500x0.05% = 0.2 lbs.
Total 16.6 lbs.

Summary of Operations

Steel Specified

Carbon	.30%	120 lbs.
Manganese	.75%	300 lbs.
Silicon	.30%	120 lbs.
Sulphur	.04%	16 lbs.
Phosphorus	.04%	16 lbs.
Iron	98.57%	39428 lbs.
Total	100.00%	40000 lbs.

Steel Made

Carbon	.302%	124 lbs.
Manganese	.740%	302 lbs.
Silicon	.387%	158 lbs.
Sulphur	.040%	16 lbs.
Phosphorus	.041%	17 lbs.
Iron	98.490%	40327 lbs.
Total	100.000%	40944 lbs.

In making high carbon steel, the specified carbon may be had by stopping the decarburization at such a time as to give the desired result by adding the then remaining carbon of the bath and the carbons of the additions, or else by adding carbon in the shape of coke or charcoal dust.

In high carbon steel of say .40% and upwards the refining of the bath is stopped when the residual carbon plus that added by the recarburizer will give a steel of the desired carbon content. Another way of securing sufficient carbon is the addition of hot metal—viz., melted pig or of pig iron or of powdered coal or coke. In the latter case coke or coal is put into the ladle immediately before tapping the heat. About 50% of the carbon enters the steel.

In low carbon steel, the residual carbon together with that of the recarburizer is sufficient in the general run.

Should the preliminary analysis before tapping show too high a carbon content this may be corrected by adding ore, in heavy enough lumps to sink into the bath and in its reduction and the boiling of the expelled oxygen effects a perfect dilution of the carbon.

Table No. 41

Efficiency of Additions to the Charge —Open Hearth Furnace Operation

Material Added	Constituent	Approx. % of the material appearing in the steel based on total weight of addition
Coal Dust..........	Carbon	45.0%
Ferromanganese....	Carbon	5.0%
Carborundum......	Carbon	20.0%
Pig Iron......... ..	Carbon	3.2%
Ferromanganese....	Manganese	65.0%
Spiegel............	Manganese	12.0%
Pig Iron, 1% Mn...	Manganese	.6%
Ferrosilicon, 15% Si	Silicon	10.0%
Ferrosilicon, 50% Si	Silicon	35.0%
Carborundum......	Silicon	50.0%
Sulphur............	Sulphur	60.0%

Table No. 42

Manganese Table

Ordered	Weight Ferromanganese 80% to give Manganese Ordered
.20 to .30%	140 lbs.
.30 to .40%	300 lbs.
.40 to .50%	425 lbs.
.50 to .60%	625 lbs.
.60 to .70%	750 lbs.

Table No. 43

Silicon Table

Ordered	Weight of 50% Ferro-silicon Required
.05 to .10%	145 lbs.
.10 to .15%	235 lbs.
.15 to .20%	335 lbs.
.20 to .25%	435 lbs.

Manganese and silicon tables are based on 50-ton heats

Slag

In an acid furnace the slag is formed by oxidation of the impurities in the charge with a certain amount of ferrous oxide. Its chief function in the furnace is to act as a protecting blanket over the metal to protect it against oxidation from the flame. Chemically, an acid slag is a double silicate of manganese and iron, with a possible very small amount of silicate of calcium. Should a high silicon iron with a comparatively small amount of scrap be charged the slag would be too thick to admit of ready penetration of heat to the metal. A reversal of the proportion of the iron and scrap would provide too thin a covering and an excessive amount of iron would be oxidized.

A basic slag is made up of the impurities of the iron as in acid furnace, together with an addition of lime to take up the phosphorus of the charge. The resulting slag is made up of silicate of manganese, iron, calcium and phosphate of calcium. When the action is a desulphurizing one, sulphide of manganese appears in the slag.

Typical slags have the following approximate average composition:

Table No. 44

Open Hearth Slags

	Acid Furnace	Basic Furnace
SiO_2	45%	20%
MnO	17%	10%
FeO	35%	16%
CaO	3%	42%
MgO		8%
P_2O_5		4%
Total	100.0%	100.0%

Method of Charging

It has been suggested that the procedure should be first charging scrap and then the pig on top. This protects the scrap from oxidation by the iron trickling down over the scrap. The oxygen of the flame thereby combines with the carbon, silicon and manganese of the pig rather than the otherwise unprotected iron of the scrap. This is by no means the usual practice.

The almost universal practice is to charge the pig first and on it put the scrap. Some charge pig then scrap and on top the remainder of the pig.

Placing the pig on the hearth protects it from the oxide of iron made from the scrap, which otherwise would form with the sand bottom a silicate of iron, causing a rapid cutting of the hearth.

With very heavy scrap there is little advantage of one method over the other, but with light thin plate scrap oxidizing quickly, the danger of rapid scouring the bottom and burning through becomes real.

CHAPTER XIII

Open Hearth Furnace Design

The history of iron and steel manufacture has been one of development of apparatus and methods through the teachings of experience gained by the practical furnaceman. Scientific work points the way to improving the quality, increasing the production tonnage and to decreasing the cost of steel. The ultimate test of the quality of steel is its use.

Rigid mathematical formulae cannot control open hearth furnace design as completely as may be possible in some other lines of engineering.

The successful designer and builder of open hearth steel works must found his practice upon a thorough personal knowledge of steel metallurgy including furnace construction and operation, and the working of the metal in the rolling mill or under the press or hammer.

The accepted forms and dimensional relations existing between the several parts of an open hearth furnace are those which long years of operation have demonstrated as the best approximations to perfectly successful steel making conditions. For over fifty years, highly skilled men in many countries have given their best efforts to reach the conclusions given in the accompanying tabulation of furnace dimensions.

The expected performance of a proposed furnace is predicted by a comparison with the past record of furnaces as nearly similar to the new furnace as possible. The proportions are usually expressed in areas or volumes per ton of product.

The prime dimensions are those of the hearth in which the steel is made. A basic furnace will require a larger hearth than an acid furnace on account of the greater amount of slag made.

An important factor in fixing the hearth area is to secure a large enough "laboratory" or steel making part of the furnace in which to secure perfect combustion of the fuel and absorption by the bath of the maximum amount of heat. Otherwise heat is lost and in passing through the parts wears them away rapidly. For this reason in a small furnace the higher ratios of the table are obtained. The Talbot type of furnace, being of very large capacity and using desiliconized and decarburized hot metal, is not restricted in this way as the size of the bath fixes the size of the "laboratory" beyond the lower limits required for satisfactory thermal action.

The practical economical limits to the width of the hearth is about 17′-0″, being controlled by the following conditions. After pouring a heat, the furnace men make minor repairs to the hearth and walls by throwing refractories, on hand shovels, into the badly worn places. The limit of effective patching has been reached in a furnace 17′-0″ wide. Also beyond that width the roof thrust upon the arch skewbacks as well as the pressure on the arch brick exceeds at the high furnace temperatures the strength of the brick.

In making "high speed" steel a furnace should be used in which the ratio of width

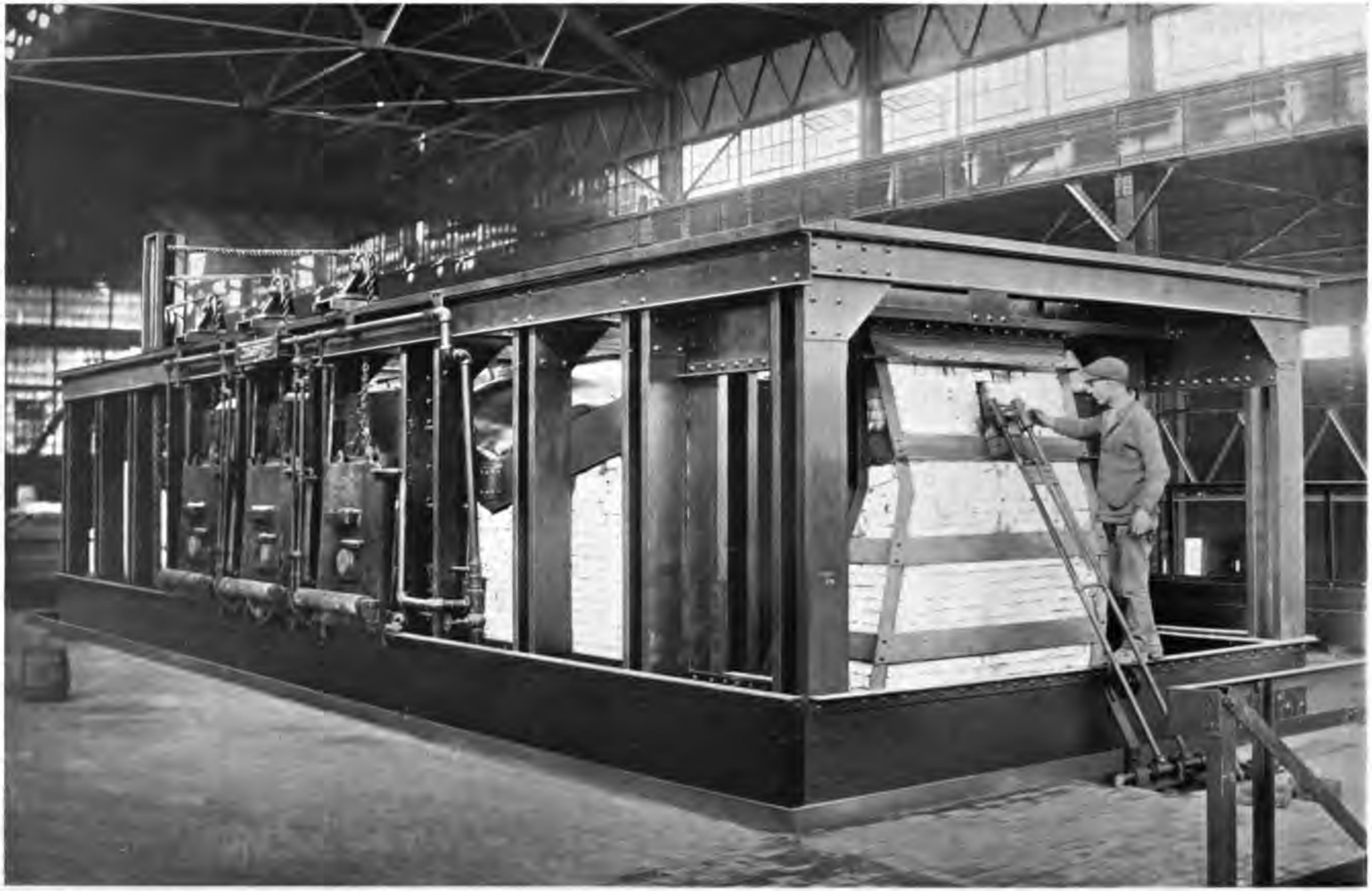


Figure 34—A 20-TON ELECTRICALLY OPERATED WELLMAN TILTING FURNACE

This furnace installed at the Atlas Crucible Steel Works, Dunkirk, N. Y., makes special high speed steel. Oil is used for fuel. The electrically operated doors are water cooled as are the door jambs and arch plates.

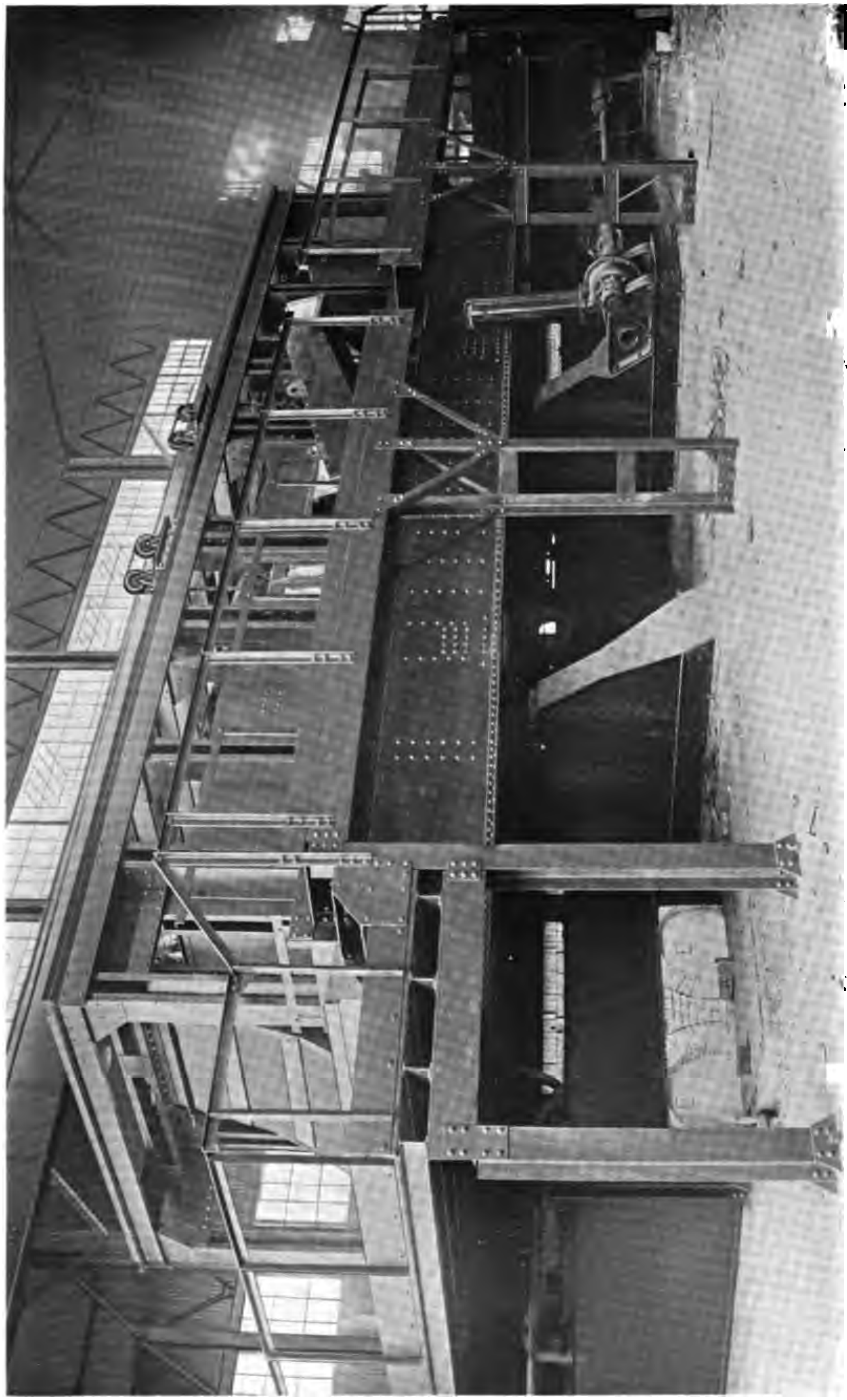


Figure 35—OIL BURNING TILTING FURNACE

Pouring side of the twenty-ton furnace shown on page 120. At the right is seen the electric tilting mechanism by which the operator may incline the furnace and hold it at any desired angle.

Table No. 45

Usual Hearth Dimensions

	Furnace Capacity Tons	Length		Width		Depth	Ratio of Length to Width	Hearth Area per ton	
								Square Feet	
								Country	
		Ft.	Ins.	Ft.	Ins.	Ins.		U.S.A.	England
Maximum	100	40	0	17	0	20	3.2	10.5	
Minimum	1					8	1.8	5.75	
Average	20-60						2.0-2.5	8.3	Acid 5to6 Basic 6to8
Talbot Type	200-250	40	0	17	0	30	2.4	3.5	

Table No. 46

Variations found in Furnace Proportions

50-Ton Furnaces—By Various Designers

Hearth			Gas Regenerator Checker Volume			Air Regenerator Checker Volumes				Ports								Valves	
										Gas				Air					
L'gth	W'dth	Area Per Ton	Dimensions	Total	Per Ton	Dimensions	Total	Per ton	Total Checker Volume Per Ton	No.	Size	Area		No.	Size	Area		Gas Dia.	Air Dia.
												Total Sq. Ft.	Per Ton			Total Sq. Ft.	Per Ton		
Ft. In	Ft. In.	Sq. Ft.		Cubic Ft.			Cubic Ft.											Inches	
26 9	12 7	6.73		1900	38														
27 0	14 0	7.5	22'-0"x6'-0"x8'-6"	1122	22.4	22'-0"x10'-0"x8'-6"	1870	37.4	59.8										
32 0	13 0	8.3	23'-6"x12'-0"x8'-6"	2397	47.9	35'-0"x11'-6"x8'-6"	3421	68.4	116.3	1	6'-0"x1'-6"	9	.18	1	6'-0"x2'-3'	13.5	.27	42	42
34 0	12 8	8.6	24'-6"x7'-0"x14'-0"	2401	48	24'-6"x10'-9"x14'-0"	3687	73.7	121.7	2	2'-5"x1'-6"	7.6	.15	2	2'-4"x1'-6"	7.0	.14	42	48
29 0	16 0	9.3	17'-0"x10'-1"x14'-6"	2485	49.7	17'-0"12'-1"x14'-6"	2979	59.5	109.2										
31 0	13 0	10.0				12'-0"x12'-0"x13'-9'	2640	52.8		1	3'-3"x1'-4"	4.3	.08	1	5'-5"x1'-8"	10.8	.21		

of hearth to its length is greater, and depth of bath is less than usual. For such a steel should be "flat" or "quiet" in the furnace, ladle and mould; that is, free from occluded gases. A wide furnace gives opportunity for the flame to spread and secure even melting. The shallow bath tends to avoid occlusion of gases and diminishes the collection together of the heavy metals such as tungsten in the lower part of the bath. The melting efficiency is higher and more uniform in a shallow bath.

The record of the Wellman-Seaver-Morgan Company's furnaces for fast working have been due to a well balanced combination of the dimensions of the hearth, laboratory, ports and regenerators. As evidenced in the following tables and diagrams illustrating their standard of furnace dimensions, there is an orderly progression in size as the steel capacity of the furnaces increases.

Roof

The roof must be made of the very best grade of silica brick as the life of a furnace is governed by the life of its roof. The remainder of the furnace can be patched between heats. The wearing of the roof may proceed until about three inches of the original brick are left. Therefore a roof of 12" has a greater steel tonnage potentiality to its credit than a 9" roof. The roof must be kept at an ample height above the bath to permit complete combustion of the fuel gas above the slag and metal. In the Wellman furnaces, the skewbacks receiving the roof arch thrust are carried in heavy steel channel beams riveted to and forming a part of the frame and binding. This binding is rigidly held in place by riveted cross channels instead of the more commonly used screwed tie rods. Thus there is no possibility of the arch flattening or dropping when expanded by the high furnace heat. The expansion is upward throughout the arch, and the line of arch thrust lies more nearly along the neutral axis of the arch, and liability of spalling of the brick along the joints is decreased.

The surfaces of all gas and air passages must be made as smooth as possible to avoid undue frictional losses in the flow of gases. For the same reason, sharp corners, abrupt entrances and exits to flues and gas passages must be avoided wherever possible.

Ports

The proper working of the furnace is largely dependent upon the form, position and size of the ports. The scouring action of the waste gases, at a high temperature and velocity, and laden with particles of slag, ore, and flux, tends to cut away the brickwork very rapidly.

Good practice requires the delivery of the air towards the top of the furnace. This insulates the roof from the intense heat of combustion, and prevents excessive oxidation of the metal of the charge, for the oxygen absorbing flame interposes. The slope of the ports should be such as to secure an intimate mixing of the air and gas at a height of about 3'-0" above the bath.

At the bottom of the flues leading up to the ports, slag pockets of ample size must be provided to catch flue dirt and prevent it being carried from the furnace into the regenerators.

Regenerators

Without the regeneration of the waste flue gas heat first applied by the Siemens brothers, it would be impossible to secure the degree of heat necessary for open hearth operation. The limit of temperature possible by effective operation is the critical temperature of the brick of which the regenerators are built.

Clay fire brick only are used, it having been found that silica checkers crumble away too fast. Recent practice leans to the use of standard 9 inch x 4½ inch x 2½ inch brick instead of smaller special shapes for the checker brick.

A discussion of the volume of gas and air at the regenerator temperatures required shows that while in many cases an allowance of 65 to 140 cu. ft. of regenerators per ton of steel is needed that good "practice" is had with 90 cu. ft. per ton. Of this one-third is given to the gas and two-thirds to the air checkers. The volume can be materially reduced if oil or natural gas are used as these fuels are not regenerated.

In the design of regenerators, the following items must be carefully considered:

1. As many checker brick should be put into the chambers as possible to allow storing a maximum amount of heat from the waste gases, without an undue increase in gas velocity.
2. A maximum of surface should be exposed.
3. The disposition of the checkers should be such as to have an intimate contact with the gases and air.
4. The design must have a uniform volumetric capacity for the flow of air and gases through the various openings in the checkers.
5. The material used and the size and structure of the checker brick must be adequate to carry the super-imposed load on them at high temperatures.
6. Means for securing increased velocity of flow at salient points, so as to avoid flue dust deposits. This dust glazes over the brick surface and destroys their thermal qualities, in addition to cutting down the cross section of the passages.

Reversing Valves

Reversing valves on the air and gas flues are operated every time the fuel is changed from one end to the other of the furnace. This occurs from three to four times an hour. The requirements of such valves are that they shall be easily and quickly operated, by simple means, shall not be worn or warped by the heat, and shall be rugged, not likely to be clogged with tar or soot, and to require little attention. Nor should the valves require an appreciable increase in flue construction. These requirements are met by the W-S-M Gas Reversing Valve. (Description in chapter XXI, page 253.)

Furnace Doors

The use of cast steel, brick lined, water cooled and counterbalanced doors and water cooled door jambs and arch castings has been found advantageous. The water cooling relieves to a considerable extent the discomfort of the men in working the furnace and prolongs the life of the brick lining of the doors. It has been found that less than 300 gallons of cooling water per door, for a 20-ton furnace is required hourly for this work, after which use if desired the hot waste water can be used for boiler feeding or other purposes.

In the Wellman designs the electric or hydraulic door operating and tilting of the furnace, the reversal of the gas valves and adjustment of fuel oil combustion, and operation of the chimney damper are all under the control and manipulation of one man standing at a place on the charging floor where he can observe the working of the furnace.

Charging the Furnace

The cheapest, most durable, and convenient charging boxes for delivering the charge into the furnace are the W-S-M open hearth cast steel boxes. (Page 273). These, while fairly light, are so rigid as to withstand rough usage and outlast many times any other style of charging box. They are made in various sizes to serve all furnaces.

Recording Instruments

The use of recording instruments and gauges is strongly advocated to show pressure, temperature, and quantity of fuel used, draft, time of reversals of the valves and other operations affecting the quality and quantity of the furnace product.

Metallurgical engineers have studied and compared the operation of many steel plants, and found marked differences in the design of details, many of which are inexplicable in the light of good operation.

The designing of a steel works building must be worked out to accommodate not only the customary static stresses but also the more serious ones of the heavy moving loads of ladles of liquid metal.

Tables and plotted curves giving governing dimensions of important features of open hearth furnace design are given. A rigid adherence to these dimensions is not always advisable, due to local conditions, the kind of fuel used, viz., oil, natural or producer gas, and the propriety of using standard sizes of certain articles such as valves, rather than demanding special sizes at a considerable advance in cost without corresponding operating advantage.

Water Cooling of Open Hearth Furnaces

Water cooling of doors, jambs and arch plates is advisable on the ground of assisting the furnace crew in working the heat and quickly doing the patching after pouring. The comfort thus given the men permits of fast working and shortening of time when the furnace is idle. The door lining of brick which is but the width of one brick in thickness last longer when water-cooled.

The flow of heat through furnace walls is proportional to the difference between the interior and exterior temperatures. The spe-

Table No. 47

Brick List for a 75-ton Basic Open Hearth Furnace

Subject to variation according to the particular design used

	Magnesite	Silica	Clay Fire Brick			"Red" or Common Brick	Total Brick (P'cs)	Total 9" Equivalents
			1st Quality	2d Quality	3d Quality			
2 Gas Producers			5,300			7,450	12,750	12,750
Gas Mains					31,870		31,870	31,870
Furnace	20,800	10,850	16,000				47,650	47,650
Roof		6,484					6,484	11,815
Ports and Gas Arches		12,200					4,250	8,360
Slag Pockets and Uptakes		127,700	11,000			30,000	139,950	142,286
Necks		12,890	5,500			15,000	33,390	36,172
Regenerators		540	161,870			110,000	272,410	281,032
Checkers			45,450				45,450	100,665
Flues				47,800	27,800	100,000	175,600	175,600
Stack					56,250	25,000	81,250	81,250
Supporting Piers						73,000	73,000	73,000
Total	20,800	170,664	245,120	47,800	84,050	353,000	924,054	1,002,450
Grain Magnesite or Syndolag								
Silica Cement		51,200 lbs.					51,200 lbs.	
Fire Clay			79,600 lbs.	15,600 lbs.	27,400 lbs.		122,600 lbs.	
Portland Cement						635 bbls.	635 bbls.	
Lime						212 bbls.	212 bbls.	
Sand						212 cu.yds.	212 cu.yds.	

Mortar for—
1000 "Red" Brick—300 lbs. Silica Cement to lay 1000 9" "Straights," Silica Brick.
1.8 Bbl. P. Cement—325 lbs. Fire Clay to lay 1000 9" "Straights," Clay Fire Brick.
.6 Bbl. Lime.
.6 Cu. Yd Sand.
1000 Brick = 56 Cu. Ft.
14 Brick = 1 Sq. Ft. of 9" Wall.

A 9 inch x 4½ inch x 2½ inch Firebrick is called a "Standard" or a "Straight" Brick.

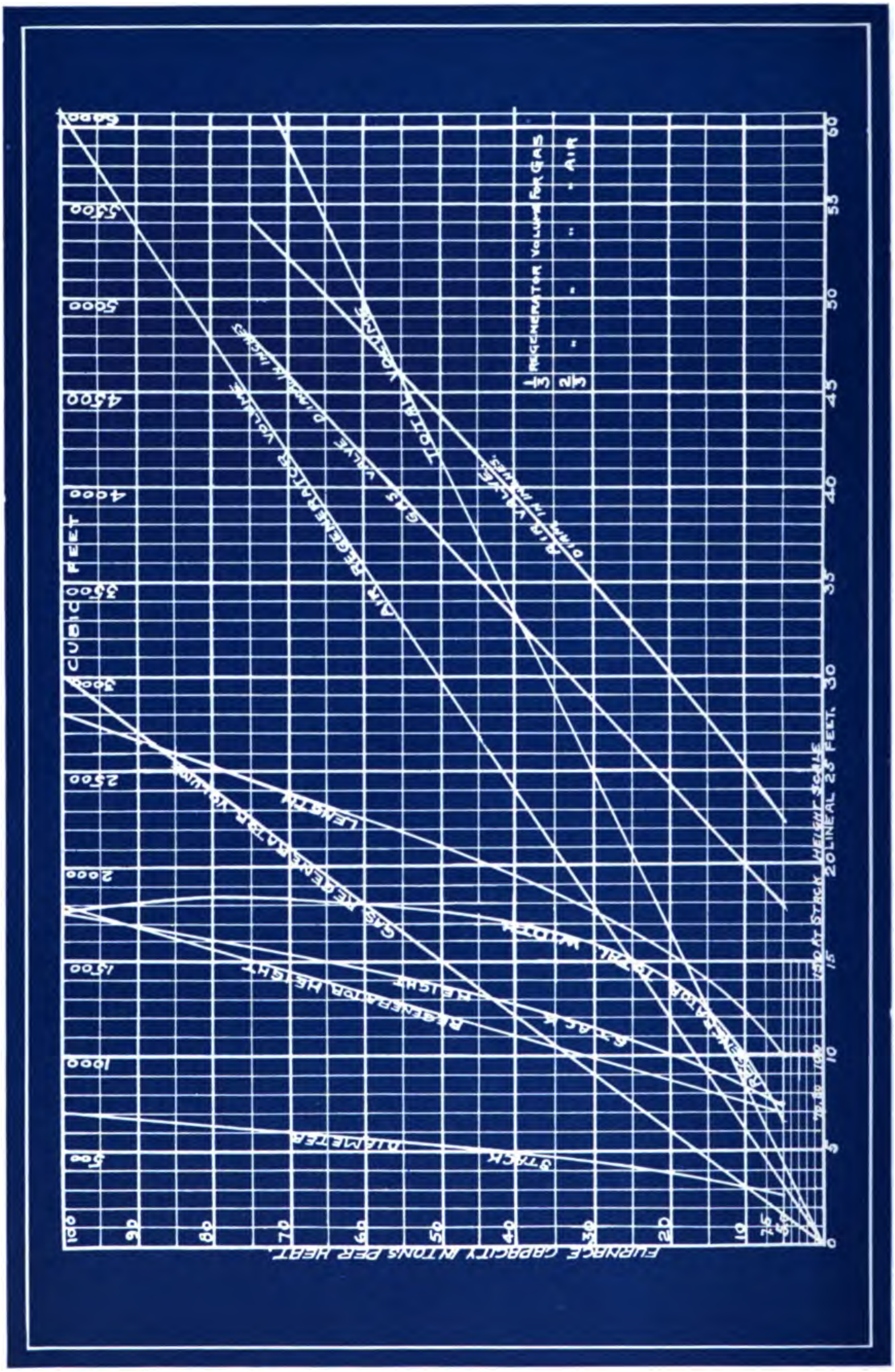
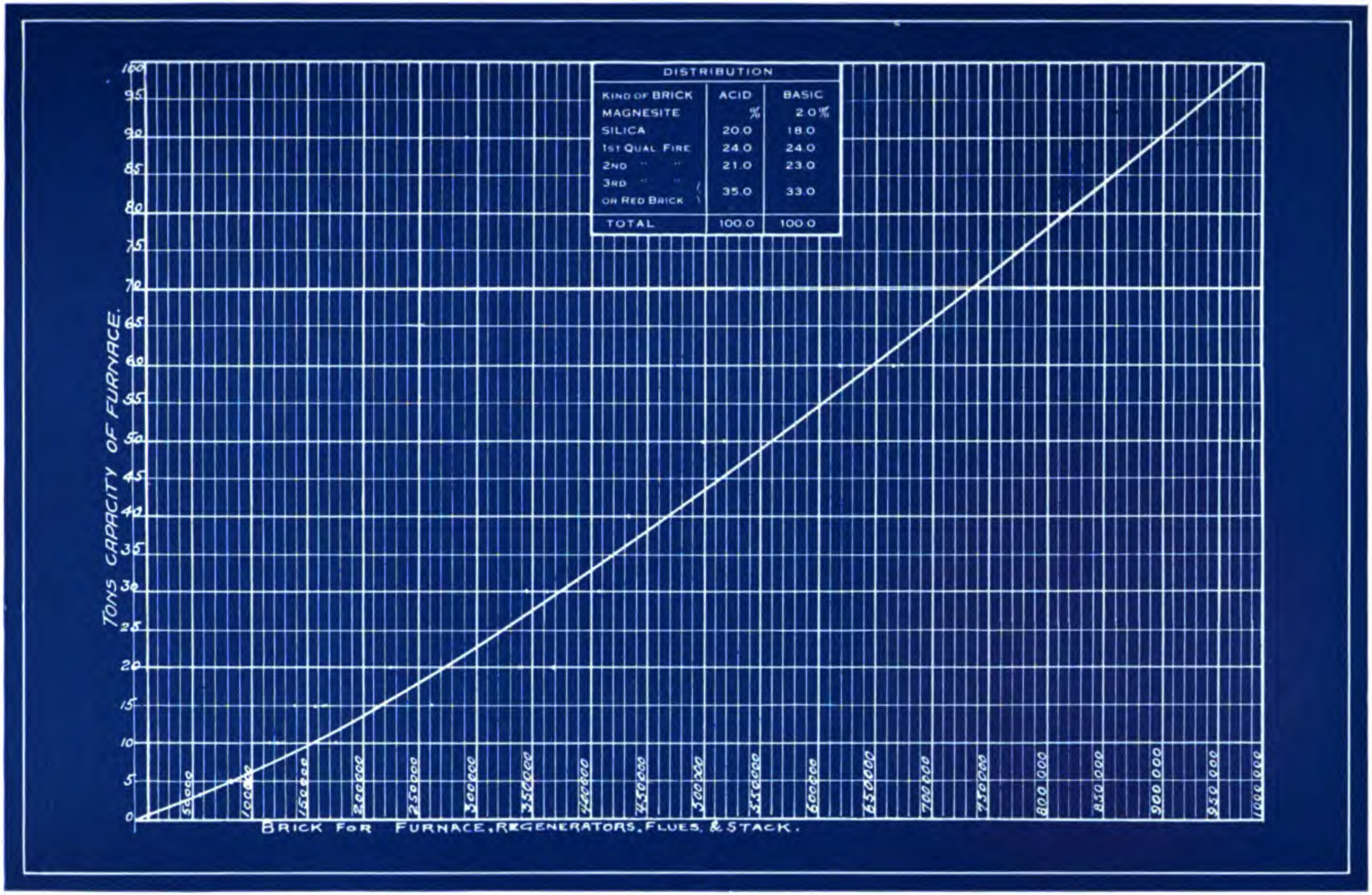


Figure 36—DIAGRAM OF THE DIMENSIONS OF THE REGENERATORS, VALVES, STACKS



DISTRIBUTION

KIND OF BRICK	ACID	BASIC
MAGNESITE	%	2.0%
SILICA	20.0	18.0
1ST QUAL. FIRE	24.0	24.0
2ND " "	21.0	23.0
3RD " " OR RED BRICK	35.0	33.0
TOTAL	100.0	100.0

Figure 37—DIAGRAM OF BRICK FOR OPEN HEARTH FURNACES
Subject to variation according to actual design.

cific heat or heat absorbing capacity of water is four times that of air and the temperature of water is generally lower than that of air in the immediate neighborhood of the furnace. Therefore, cooling of a furnace lining or its several parts such as buck-stays, ports and doors is done at an expenditure of fuel and producer labor and is a direct charge against the cost of the steel output of the furnace.

The duration of a campaign in a furnace of correct proportions and form of "laboratory" and ports is limited more by the life of the roof than by any other part of the brickwork. The time of repairs during which the furnace is down is not materially extended as compared with a water cooled furnace, as these repairs are made simultaneously with the other repairs.

The saving by water-cooling is due to the extended life of the brick thus cooled, provided other repairs do not end the furnace campaign. The log of a two weeks run on two 100-ton furnaces furnishes direct evidence as to the excess fuel cost due to cooling the ports.

A two weeks run of these furnaces showed that water cooling of the ports was accompanied by an increase in fuel consumption of 5%. An abstract of the record follows:

Table No. 48

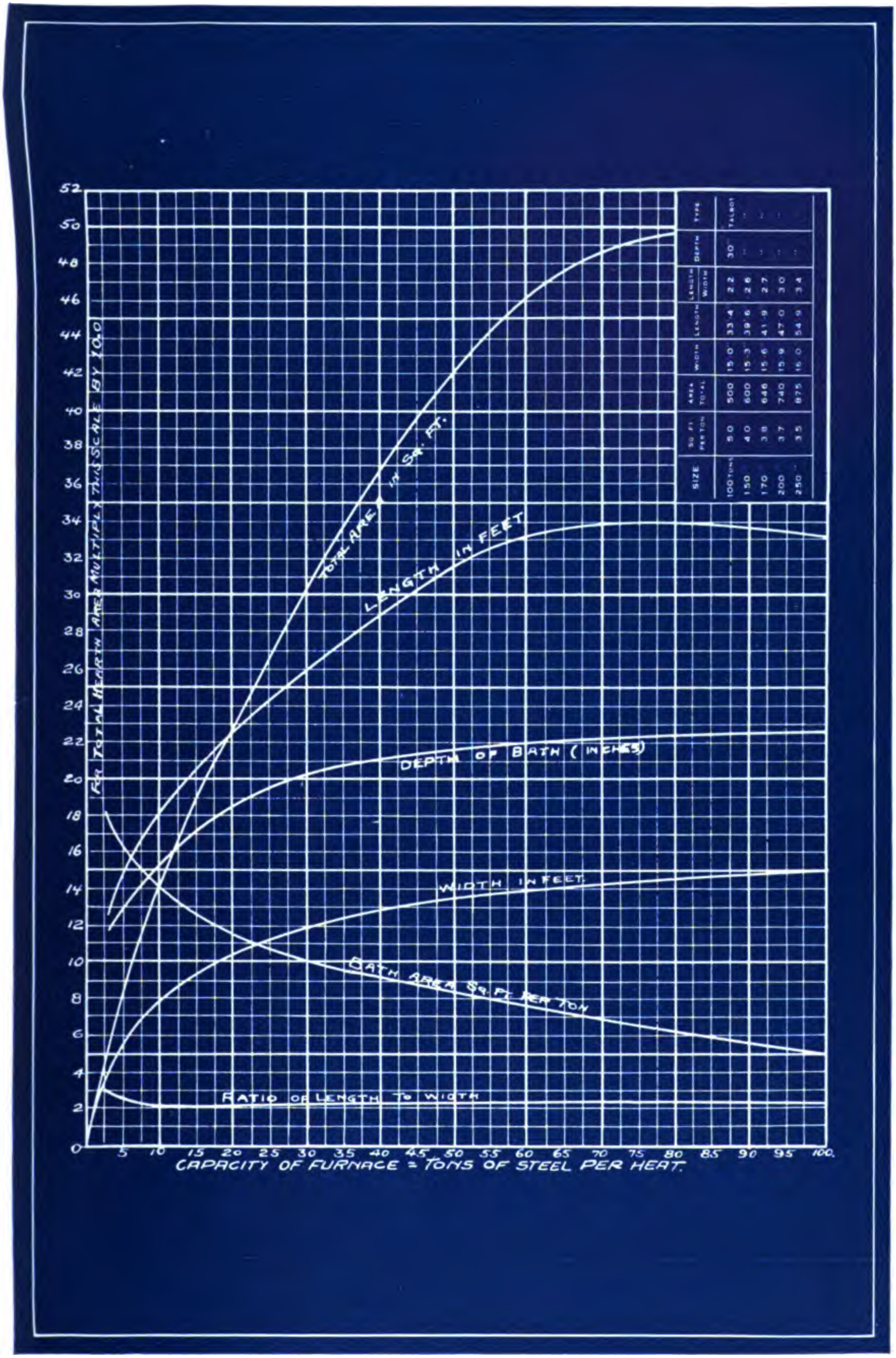
Water Cooled and Dry Ports

Furnace	A	B
Style of ports	Water-cooled	Dry
Time of Observation	Oct. 16-31 inc. 1919.	
Length of time	2 weeks	
Number of heats	25	25
Steel made	2537 tons	2519 tons
Steel made per heat	101.88 tons	100.76 tons
Average time	13h. 47m. 12 sec.	13h. 50m. 48 sec.
Average time per heat	13h. 29m. 58 sec.	13h. 43m. 36 sec.
Gas Coal Consumed per heat	70,128 lbs.	66,780 lbs.
Gas Coal Consumed in excess	5.0%	

Table No. 49

Hearth Dimensions of Open Hearth Furnaces

Capacity Per Heat	Area		Width		Length				Corresponding Area	Length / Width	Depth
	Per Ton	Total									
Tons	Square Feet		Ft.	Ins.	Ft.		Ft.	Ins.	Square Feet	Ratio	Inches
3	18.0	54.0	4	3	12.7	=	12	9	54.2	3.0	10
5	16.3	81.5	5	9	14.18	=	14	3	81.9	2.5	13
6	16.0	96.0	6	3	15.35	=	15	4	95.9	2.45	13.5
7.5	15.0	112.5	7	0	16.08	=	16	0	112.0	2.3	14
10	14.0	140.0	7	9	18.08	=	18	0	139.5	2.3	15
15	12.75	191.3	9	3	20.68	=	20	9	191.9	2.3	17
20	11.5	230.0	10	3	22.40	=	22	6	231.0	2.2	18
25	10.8	270.0	11	0	24.55	=	24	6	270.0	2.2	19
30	10.0	300.0	11	9	25.50	=	25	6	300.0	2.2	20
35	9.7	339.5	12	6	27.10	=	27	0	338.0	2.2	21
40	9.3	372.0	12	9	29.20	=	29	0	370.0	2.3	21
50	8.5	425.0	13	6	31.50	=	31	6	426.5	2.3	22
60	7.7	462.0	13	9	33.60	=	33	6	461.0	2.45	22
65	7.2	468.0	14	0	33.45	=	33	6	469.0	2.4	22
70	6.9	483.0	14	3	33.90	=	34	0	484.0	2.4	22
75	6.6	495.0	14	6	34.10	=	34	0	494.0	2.35	22
80	6.2	496.0	14	7	34.10	=	34	0	495.0	2.3	23
90	5.5	495.0	14	9	33.60	=	33	6	495.0	2.3	23
100	5.0	500.0	15	0	33.30	=	33	4	500.0	2.2	30
150	4.0	600.0	15	3	39.40	=	39	6	600.0	2.6	30
160	3.8	608.0	15	3	39.90	=	40	0	610.0	2.65	30
170	3.8	646.0	15	6	41.70	=	41	9	646.0	2.7	30
200	3.7	740.0	15	9	47.00	=	47	0	740.0	3.0	36
250	3.5	875.0	16	0	54.00	=	54	9	878.0	3.4	36



SIZE	SQ. FT. PER TON	AREA TOTAL	WIDTH	LENGTH	LENGTH / WIDTH	DEPTH	TYPE
100 TONS	5.0	500	15' 0"	33' 4"	2.2	30"	TALBOT
150	4.0	600	15' 3"	39' 6"	2.6	"	"
170	3.8	646	15' 6"	41' 9"	2.7	"	"
200	3.7	740	15' 9"	47' 0"	3.0	"	"
250 "	3.5	875	16' 0"	54' 9"	3.4	"	

Figure 38—DIAGRAM OF HEARTH DIMENSIONS

Table No. 50

Hearth Dimensions—Existing Open Hearth Furnaces

Wellman and other designs

Works	Type	Capacity Tons	Area Total	Area Per Ton	Length		Width		Depth	Ratio of Length Width	Fuel
			Square Foot		Ft.	Ins.	Ft.	Ins.	Ins.		
J. A. & P. E. Dutcher, Milwaukee	Tilting	3	37.3	12.4	9	0	4	3	10	2.1	P. Gas
The Prescott Co.	Tilting	5	80.5	16.1	14	0	5	9	16	2.4	Oil
The Crane Co.	Tilting	5	80.5	16.1	14	0	5	9	18	2.4	Oil
Firth-Stirling Steel Co.	Tilting	5	80.5	16.1	14	0	5	9	24	2.4	P. Gas
The Crucible Steel Co.	Tilting	6	92.0	15.3	16	0	5	9	14	2.8	P. Gas
Reichizta, Austria †		10	101.0	10.1	13	6	7	6.5		1.8	P. Gas
Germany †		15	187.	12.8	19	0	9	10		1.9	P. Gas
Hamilton I. & S. Co., Canada	Tilting	15	180.	12	20	0	9	0	8	2.2	P. Gas
Shickle-Howard-Harrison, St. Louis	Tilting	15	180.	12	20	0	9	0	9	2.2	P. Gas
Atlas Crucible Steel Co., Dunkirk, N.Y.	Tilting	15	180.	12	20	0	9	0	15	2.2	Oil
U. S. Arsenal, Watertown, Mass.	Tilting	15	348.	10	29	0	12	0	16	2.4	Oil
Wellman-Seaver-Morgan, Cleveland, O.	Tilting	20	220.	11	22	0	10	0	13	2.2	Oil
Wellman-Seaver-Morgan, Cleveland, O.	Stat'y	20	273.	13.6	27	4	10	0	14	2.7	P. Gas
Marion Steam Shovel Co., Marion, O.	Stat'y	20	230.	11.5	23	0	10	0	12	2.3	Oil
Vulcan Loco. Works, Wilkes-Barre, Pa.	Tilting	20	230.	11.5	23	0	10	0	12	2.3	Oil
Austria †	Stat'y	30	270.	9.0	27	0	10	0	26	2.7	P. Gas
Illinois Steel Co.		30	286.	8.9	21	10.5	12	3		1.7	P. Gas
Brymbo, England	Tilting	30	299.	9.9	26	0	11	6	24	2.3	P. Gas
Brown-Bailey, England	Tilting	30	380.	12.7	33	0	11	6	24	2.9	P. Gas
Talbot, Spain	Tilting	30	299.	10.0	26	0	11	6	20	2.3	P. Gas
Wickwire Bros., Cortland, N. Y.	Tilting	30	322.	10.7	28	0	11	6	15	2.4	P. Gas
U. S. Arsenal, Watertown, Mass.	Stat'y	35	348.	10.0	29	0	12	0	16.5	2.4	Oil
Shoenberger †		35	348.	10.0	29	0	12	0		2.4	
Atlanta Steel Hoop Co., Atlanta, Ga.		35	357.	10.1	31	0	11	6	12	2.7	P. Gas
Carnegie Steel Co., Homestead †	Monell	40	329.	8.2	26	4	12	6		2.1	
Penna. Steel Co., Steelton, Pa. †		40	210.	5.2	20	0	10	6	30	1.9	
Grand Crossing Tack Co., Chicago	Stat'y	40	360.	9.0	30	0	12	0	15	2.5	P. Gas
Tenn.Coal, Iron & R.R.Co.,Ensley, Ala.	Tilting	50	429.	8.6	33	0	13	0	20	2.5	P. Gas
N. Scotia Steel Co., New Glasgow, N.S.	Tilting	50	429.	8.6	33	0	13	0	18	2.5	P. Gas
Penna. Steel Co., Steelton, Pa. †		50	370.	7.4	32	0	13	0	32	2.5	P. Gas
Penna. Steel Co., Steelton, Pa. †		50	320.	6.4	32	0	10	0		3.2	
Barrow, England		50	287.	5.7	28	0	13	3		2.7	
Carnegie Steel Co., Sharon, Pa. †		50	420.	8.4	29	0	14	6	33	2.0	
Carnegie Steel Co., Duquesne, Pa. †		50	378.	7.6	27	0	14	0	18	1.9	
Imperial Arsenal, Kure, Japan	Tilting	50	429.	8.6	33	0	13	0	15	2.5	P. Gas
Hazleton, Pa.		60	510.	8.5	34	0	15	0		2.3	P. Gas
Lackawanna Steel Co., Buffalo, N. Y. †		60	720.	12.0	43	0	16	9		2.6	P. Gas
Pencoyd, Pencoyd †	Talbot	70	270.	3.9	30	0	9	0		3.3	
48447	Talbot	75	551.	7.3	38	0	14	6	21	2.6	P. Gas
Frodingham I. & S. Co., England	Talbot	100	384.	3.8	32	0	12	0		2.7	P. Gas
Talbot, England	Talbot	100	442.	4.4	34	0	13	0	30	2.6	P. Gas
Lackawanna Steel Co., Buffalo, N. Y. †	Talbot	100	520.	5.2	40	0	13	0		3.1	P. Gas
Guest-Keene & Co., England	Talbot	160	600.	3.8	40	0	15	0	30	2.7	P. Gas
Witkowitz, Moravia †	Talbot	200	581.	3.85	47	3	12	4	22	3.8	
Tenn.Coal,Iron & R.R.Co.,Ensley,Ala.	Talbot	200	570.	2.35	38	0	15	0	51	2.5	P. Gas
Illinois Steel Co., So. Chicago †	Talbot	200	644.	3.28	40	0	13	6	45	3.0	P. Gas
Imperial Arsenal, Japan *	Talbot	200	640.	3.2	40	0	16	0	36	2.5	P. Gas

† Not of Wellman design.

* Under contract for construction.

Table 51—Rating of American and Continental Open Hearth Furnaces (*Iron Trade Review*)

Furnace	Capacity in Tons	Width Inside Lining	Length between blocks	Sq. Ft. Bottom per Ton	Acid or Basic	Gas Regenerators					Air Regenerators					Size and Area of Gas Uptakes	Size and Area of Air Uptakes	Sq. In. per Ton in Gas Uptakes	Sq. In. per Ton in Air Uptakes	Gas Ports			Air Ports			Valves				Chimney		Remarks
						Dimensions of Checker Work			Capacity in Cu. Ft.	Cu. Ft. Per Ton	Dimensions of Checker Work			Capacity in Cu. Ft.	Cu. Ft. Per Ton					Dimensions	No.	Area	Dimensions	No.	Area	Gas		Air		Inside Dia.	Height	
																										Size	Type	Size	Type			
		Ft. In.	Ft. In.			Ft. In.	Ft. In.	Ft. In.			Ft. In.	Ft. In.	Ft. In.							Ft. In. Ft. In.		Sq. In.	Ft. In. Ft. In.		Sq. In.	In.		In.		Ft. In.	Feet	
American Furnaces																																
d[1]	250	16-6	41-6	2.73	~	21-0	7-6	15-9	2480.6	9.32	21-0	12-4½	15-9	4095	16.38			—	—	—												Talbot Furnace
e[2]	200	14-6	40-0	2.9	~	29-0	9-6	21-0	5786.0	28.93	29-0	12-6	21-6	7612	38.06			—	—	—												Chambers found too large & subsequently considerably reduced — Talbot Furnace
f[2]	200	16-0	40-0	3.2	~	25-0	8-0	12-0	2400.0	12.0	25-0	11-0	12-0	3300	16.5			—	—	—												Talbot Furnace
g[2]	100	15-0	39-8	3.96	~	25-9	8-7	17-9	[illegible]	26.08	25-9	14-8	17-9	[illegible]	[illegible]			—	—	—												
h[2]	60	16-9	43-0	12.0	~	22-3	8-2	13-4	2417.0	40.28	20-8	14-2	14-4	4196	69.96			—	—	—												
i	60	13-6	36-0	8.10	Basic	16-0	6-6	14-0	1458.0	24.30	16-0	8-6	14-0	1905	31.8	1 Uptake 30"x32"=960□"	2 Uptakes 28"x28"=1568□"	16.1	26.1	2-8x2-6	1	6.66	2-4x2-4	2	10.40	42	Dyblie	48	Butterfly	7-0	140	
j	50	13-0	52-0	8.32	~	23-6	12-0	8-6	2397	47.94	35-0	11-6	8-6	3421	68.42			—	—	6-0x1-6	1	9.00	6-0x2-3	1	13.5	42	—	42				
k	50	14-0	27-0	7.56	~	22-0	6-0	8-6	1122	22.44	22-0	10-0	8-6	1870	37.40			—	—	—	~	—	~	~	—	—	—					
l	50	13-0	31-0	10.07	~	~	—	~	—	~	12-0	12-0	13-9	2640	66.0			—	—	3-3x1-4	1	4.30	6-6x1-8	1	10.83	—	—					
m	50	12-8	34-0	8.6	Basic	24-6	7-0	14.0	2401	48.02	24-6	10-9	14-0	3687	73.74	2 Uptakes 29"x30"=1740□"	2 Uptakes 28"x36"=2016□"	34.8	40.32	2-5x1-6	2	7.46	2-4x1-6	2	6.98	42	Forter	48	Forter	6-0	150	
n	50	16-0	29-0	9.28	~	17-0	10-1	14-6	2485	49.7	17-0	12-1	14-6	2979	59.58			—	—	—	—	—	—	—	—	—	—					
o	40	13-0	34-0	11.05	~	22-0	6-3	13-0	1787	44.70	22-0	8-9	13-0	2501	62.5			~	~	1-10x1-7	1	2.90	2-3x3-0	2	13.5	42	—	48				
p	40	12-6	21-0	9.68	Basic	17-0	6-6	15-0	1687	42.17	17-0	8-6	15-0	2167	54.17	1 Uptake 30"x32"=960□"	2 Uptakes 28"x30"=1680□"	24.1	42.0	2-8x2-6	1	6.66	2-6x2-4	2	11.5	36	Forter	42	Butterfly	5-6	140	
q	40	15-1¾	27-0	10.24	Basic	19-0	7-7½	13-6	1955.8	48.90	19-0	11-7½	13-6	2981.8	74.5	3 Uptakes [illegible] =1544□"	3 Uptakes [illegible] 2916□"	38.6	72.90	2-0x1-6 2-0x2-9	3	14.00	9-9x1-4½	1	12.9	—						
r	25	11-6	26-0	12.00	~	11-0	5-0	18-0	990	39.60	11-0	7-3	18-0	1435	57.4					4-6x1-0	1	4.50	6-0x1-2	1	7.00	32		36				
s	20	12-0	22-0	13.2	~	10-6	Dia.	10-6	909	45.45	12-0	Dia.	10-6	1187	59.3					1-0x1-0	2	2.00	1-0x1-0	3	3.00	30		30				
ab	20	9-8	21-0	10.8	~	12-10	8-1	10-0	1057	52.85	12-10	9-1	10-0	1165	58.25					1-1½x1-3	2	2.75	9-8x1-3	1	12.08	27		27				
Continental Furnaces.																																
t[2]	200	14-9	45-3⅜	3.34	Basic	~	~	~	~	~	~	~	~	~	~	1 Uptake 5'-0"x2'-6" 1800□"	2 Uptakes 5'-0"x2'-6"	9.00	18.0	2-1¼x2-3½	1	4.90	8-1x1-11½	1	15.94	~	[illegible]		Butterfly			Talbot Furnace
u	30	10-6	26-11	9.40	—	12-4½	9-10	14-0	1788	59.60	11-5	10-11	14-0	1770	59.0			—	—	1-11½x1-3¾	2	5.16	5-3x1-2	1	6.08	36		36				
v	25-30	11-1	24-7	12.18	~	13-1	5-3	10-2	697	25.34	13-1	9-4	10-2	1239	45.08			~	~	1-3½x0-11⅝	~	1.87	11-1¾x0-11¾	~	10.90			37				
w	15-18	11-2	21-3	13.08	~	10-3	6-2	10-1⅝	639	38.72	10-3	9-2	10-1⅝	961	57.51			~	~	1-3½x0-11⅝	—	1.87	10-2x1-2⅞	~	12.60			37				
x	40	11-8	30-0	8.74	Basic	22-6	7-0	9-0	1396	34.90	22-6	10-9	9-0	2178	54.45	2 Uptakes 49"x21"=2058□"	2 Uptakes 61"x27"=3294□"	51.45	82.35	1-6x1-4	2	3.98	3-8x1-0	2	7.66			~				
y	~	9-2⅞	21-4⅝	~	~	~	~	~	~	~	~	~	~	~	~			—	—	2-11½x1-5¾	2	8.58	7-10x0-11¾	1	7.75			~				
z	30	10-6	25-0	8.75	Basic	12-6	6-0	10-2	1762	[illegible]	12-6	10-0	4-4½	2633	87.77	1 Uptake 30"x30"=900□"	2 Uptakes 24"x24"=1152□"	30	38.4	3-0x1-6	1	9.00	2-4x1-5	2	6.66	30	Forter	30	Forter	6-0	138	

Dimensions of Chambers in place of Checker-work, gas + air regenerators are donated thus.² In all cases of Checkers and Ports, the sizes are given across the width of the furnace first; those going with the lengh of the furnace, second, and in case of the checkers the depth is given last The sizes of the Checkers are taken from the top of Bearers to top of bricks in all cases except those marked.¹

Table 52—Rating of English Open-Hearth Furnaces (*Iron Trade Review*)

Furnace	Capacity in Tons	Thickness Lining	Length between Blocks	Sq Ft of Bath Per Ton	Acid or Basic	Gas Regenerators: Dimensions of Checker Work			Gas Regenerators: Capacity in Cu. Ft	Gas Regenerators: Cu. Ft Per Ton	Air Regenerators: Dimensions of Checker Work			Air Regenerators: Capacity in Cu. Ft.	Air Regenerators: Cu. Ft. Per Ton	Size & Area of Gas Uptakes	Size and Area of Air Uptakes	Sq. in. Per Ton in Gas Uptakes	Sq. in Per Ton in Air Uptakes	Gas Ports: Dimensions	Gas Ports: No	Gas Ports: Area	Air Ports: Dimensions	Air Ports: No	Air Ports: Area	Valves, Gas: Size	Valves, Gas: Type	Valves, Air: Size	Valves, Air: Type	Chimney: Inside Dia.	Chimney: Height	Remarks
		Ft In	Ft In			Ft In	Ft In	Ft In			Ft In	Ft In	Ft In							Ft.In × Ft.In		Sq. Ft.	Ft.In. Ft.In		Sq. Ft.	Inches		Inches		Ft. In.	Feet	
A¹	250	16-0	42-0	2.44	Basic	20-0	8-0	17-0	2720	10.88	20-0	10-0	17-0	3400	13.6	1 Uptake [illegible]	2 Uptakes 2'-6"×5'-0"	9.0	14.4	3-6×2-6	1	8.75	8-0×2-9	1	14.2	42	Waterseal	~	Butterfly	6-6	140	Talbot Furnace
B	200	14-0	44-0	3.08	Basic	20-6	8-0	11-0	1804	9.02	20-6	10-0	11-0	2255	11.275	1 Uptake 5'-0"×3'-0" [illegible]	2 Uptakes 5'-0"×2'-3"	10.8	16.2	2-2×2-6	1	5.4	5-9×2-4	1	15.8	42	Waterseal	~	Butterfly	6-0	126	" "
C¹	150	15-0	40-0	4.00	~	22-0	8-0	9-0	1584	10.56	22-0	10-0	9-0	1980	13.2	~	~	~	~	2-6×2-8	1	4.16	2-3×2-10	2	11.04	—	~	~	~	~	~	" "
D	150	15-0	40-0	4.00	Basic	22-0	7-8	10-0	1686	11.24	22-0	9-8	10-0	2126	14.17	1 Uptake [illegible]	2 Uptakes 4-2"×2'-3"	22.6	18.0	2-3×2-1⅝	1	5.0	7-6×3-0	1	23.0	42	Waterseal	~	Butterfly	6-0	126	Hollow Billet Coils 10×6, Talbot Furnace
E¹	125	12-10	34-0	3.47	~	22-0	6-3	8-0	1100	8.80	22-0	8-4	8-0	1540	12.32	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	Talbot Furnace
F	120	13-0	26-3	3.93	Basic	4-6	Dia.	30-3	2146	17.85	9-6	30-3	—	2144	17.85	~	~	~	~	~	1	5.29	~	1	7.44	23	~	36	~	~	~	Preliminary Furnace
G	100	12-0	30-6	3.66	Basic	22-0	6-6	6-0	858	8.58	22-0	8-0	6-9	1188	11.88	1 Uptake [illegible]	2 Uptakes 2'-6"×3'-0" [illegible]	12.96	21.6	1-8×1-10	1	3.06	2-3×2-2	2	14.06	42	Waterseal	42	Butterfly	6-0	120	Talbot Furnace
H	50	13-0	28-0	7.28	Acid	12-0	9-6	9-6	1083	21.66	12-0	9-6	9-6	1083	21.66	~	~	~	~	2-0×1-6	1	3.00	2-3×1-6	2	6.6	27	~	27	~	~	~	~
I	50	11-3	28-0	6.30	Acid	12-3	9-6	9-3	1076	21.52	12-3	9-6	9-3	1076	21.52	1 Uptake [illegible]	2 Uptakes 24"×30"=1440□"	13.9	28.8	2-6×1-6	1	3.75	2-0×1-9	2	7.0	30	~	30	~	~	~	~
J	50	14-0	32-0	9.00	Acid	14-0	6-6	12-0	1092	21.80	14-0	8-6	12-0	1428	28.56	~	~	~	~	1-0×1-3	2	2.50	1-3×2-3	2	6.58	36	~	42	~	~	~	~
K	50	12-0	24-0	5.76	Basic	11-6	6-0	12-0	828	16.56	11-3	9-0	12-0	1215	24.3	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	Fuel Burned Per Hr.=1764 lbs.
L	50	13-2	28-0	7.36	Basic	16-0	7-0	17-0	1904	38.00	16-0	9-0	16-0	2304	46.3	3 Uptakes 12"×21"=[illegible]	2 Uptakes 18"×33"=1188□"	13.44	23.96	0-9×1-3	2	1.87	3-3×1-3	2	8.12	54	Double Beat	54	Double Beat	7-3	175	~
M	50	11-8	28-0	6.57	Basic	14-0	7-0	13-0	1274	25.48	14-0	9-0	12-6	1575	31.5	2 Uptakes [illegible]	2 Uptakes 18"×33"=1188□"	13.44	23.96	0-9×1-3	2	1.87	3-3×1-3	2	8.12	36	~	48	Butterfly	~	~	~
N	45	12-6	33-0	8.33	Basic	22-0	6-0	9-3	1221	27.13	22-0	6-0	9-3	1221	27.13	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	Fuel Burned Per Hr.=2240 lbs.
O	40	11-3	24-0	6.75	Acid	12-1	9-0	9-3	1006	25.15	12-1	9-0	9-3	1006	25.15	1 Uptake 30"×18½"=[illegible]	2 Uptakes 24"×18½"=888□"	13.8	22.2	1-9×1-3	1	2.18	2-4×1-6	2	6.98	29	~	29	~	~	~	~
P	40	11-3	28-0	7.80	~	18-3	7-0	13-6	779	19.23	8-3	8-0	13-6	890	22.2	~	~	~	~	16×1-2	2	3.30	6-6×1-3	1	8.66	27	~	27	~	~	~	~
Q	40	12-0	24-0	7.40	Basic	12-0	6-0	11-3	810	20.00	12-0	11-3	11-3	1519	37.9	2 Uptakes 18"×22"=792□"	3 Uptakes [illegible]	19.8	20.9	1-6×1-2	2	~	12-0×1-0	1	~	~	~	~	~	5-0	~	Fuel Burned Per Hr.=1764 lbs.
R	40	11-6	30-0	8.68	Basic	11-6	14-6	4-6	294	7.30	12-0	9-6	7-0	798	19.95	2 Uptakes 16"×14"=448□"	3 Uptakes 30"×18" & 24"×16"=[illegible]	11.2	30.0	1-0×1-2	2	2.34	2-0×1-10 1-4×1-7	3	9.20	36	Waterseal	42	Butterfly	~	—	~
S	40	10-8	30-1	8.01	Basic	12-0	7-0	7-0	604	16.20	12-0	8-6	7-0	714	17.80	2 Uptakes [illegible]	2 Uptakes 23"×18"=828□"	12.60	20.7	1-2×1-2	2	2.68	2-3×1-1	2	2.86	32	Porter	30	Butterfly	4-3	120	~
T	37	11-6	26-0	8.08	Basic	13-6	7-9	6-9	706	19.00	13-6	8-1½	6-9	744	20.10	2 Uptakes [illegible]	3 Uptakes [illegible]	12.1	32.4	1-0×1-2	2	2.34	2-0×1-10 1-4×1-7	3	4.20	26	Double Beat	42	Butterfly	~	~	Fuel Burned Per Hr.=1881 lbs.
U	35	12-2	23-6	8.10	~	10-8	7-6	9-6	760	21.70	10-8	8-6	9-6	861	24.6	~	~			1-6×2-4	1	3.00	1-6×2-3	2	7.00	30	~	33	~	~	~	~
V	30	11-0	22-0	8.06	Acid	8-0	7-0	13-9	770	25.66	8-0	7-0	13-9	770	25.66	~	~			~	~	~	~	~	~	~	~	~	~	~	~	~
W	30	11-0	24-0	8.80	Acid	13-3	7-6	12-0	1192	39.70	13-3	9-0	12-0	1431	47.70	~	~			1-2×1-7	2	3.66	1-9×0-10	3	4.38	30	~	33	~	~	~	~
X	30	10-6	26-0	9.90	Acid	13-4	6-6	5-10	505	16.83	13-4	8-0	5-9	613	20.40	~	~			1-3×1-2	2	2.91	6-3×1-4	1	8.16	27	~	30	~	~	~	~
Y	25	10-6	22-3	9.80	Basic	12-0	4-6	5-0	270	10.80	12-0	6-0	4-3	306	12.40	~	~			2-0×1-6	1	3.00	2-0×1-6	2	6.00	27	~	30	~	~	~	~
Z	25	11-0	25-6	11.20	Basic	13-0	6-11	10-2	949	37.30	13-0	7-8	10-2	1013	40.52	~	~			2-4×1-3	1	2.91	2-4×1-3	2	5.82	27	~	30	~	~	~	~
a	—	10-8	22-6	~	Basic	13-0	6-11	10-11	922		13-0	7-8	10-3	1024	—	~	~			2-0×1-1	2	4.30	2-0×1-2 2-0×1-0	3	6.33	30	~	33	~	~	~	~
b	20	9-8	24-0	11.50	~	9-4	5-0	12-0	585	29.25	9-9	7-0	12-0	819	40.95	~	~			0-10½×1-0	2	1.75	4-4×1-0	1	4.33	23	~	36	~	~	~	Temperature of Gases in Chimney [illegible]
c	20	9-8	20-0	9.66	Basic	7-6	Dia.	12-0	530	26.50	8-0	Dia.	12-0	603.12	30.15	1 Uptake 24"×24"=[illegible]	1 Uptake 33"×24"=792□"	28.8	39.6	1-0×1-2	2	2.82	5-6×9-0	1	4.12	24	~	29	Butterfly	3-6	120	

Dimensions of Chambers in Place of Checker work, gas and air Regenerators are noted thus¹ In all cases of Checkers & Ports, the sizes are given across the Width of the Furnace first; those going with the length of the Furnace, second, and in case of the checkers, the depth is given last. The sizes of the checkers are taken from the top of bearers to top of Bricks in all cases except those marked ¹

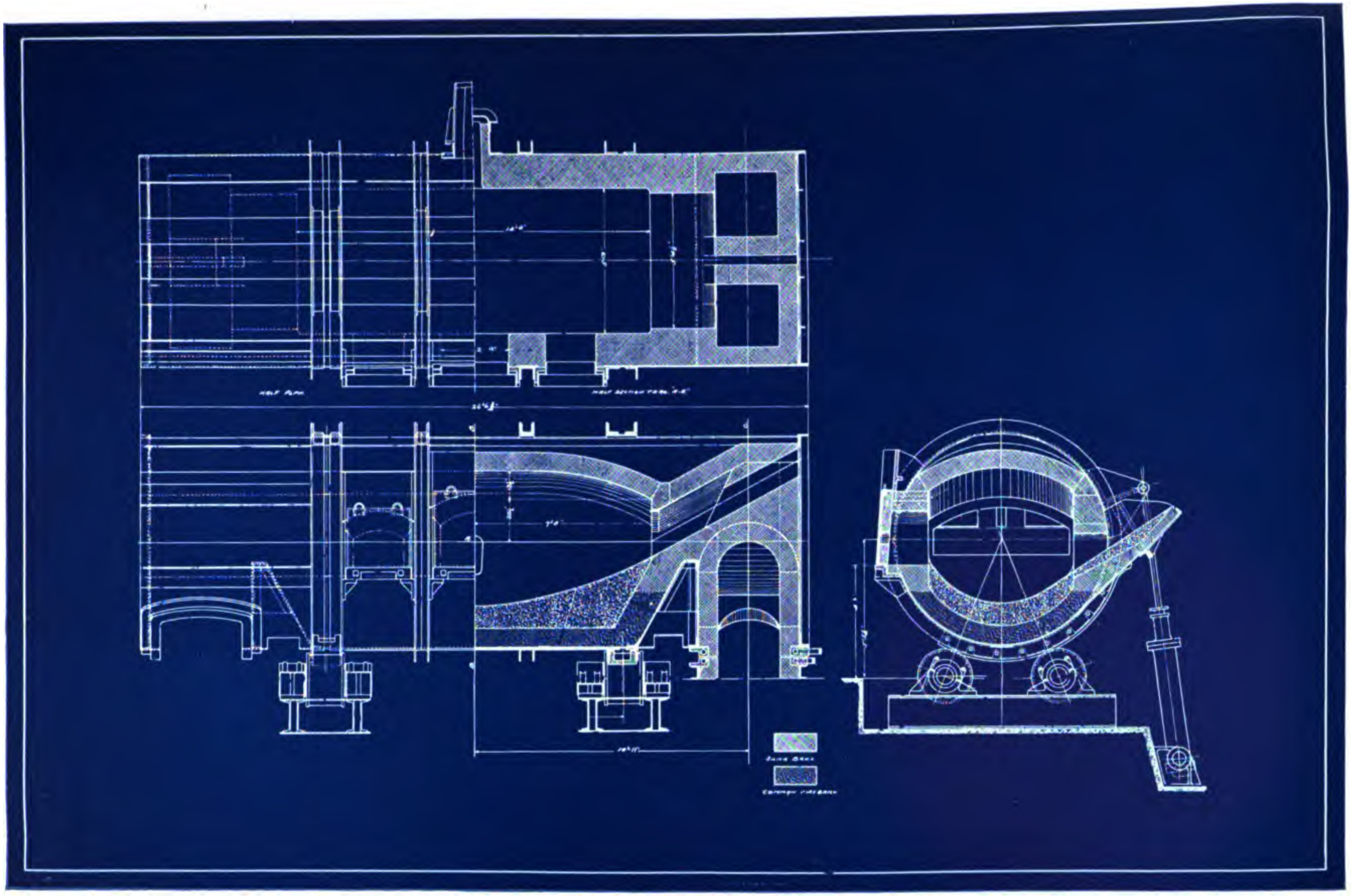


Figure 39—5-TON ACID WELLMAN OPEN HEARTH FURNACE

Built for The Crane Company, Chicago. It is hydraulic tilting and uses oil fuel. The hearth is 5 feet 9 inches by 28 feet by 1 foot 9 inches. The area of the hearth per ton of capacity is 32.2 square feet.

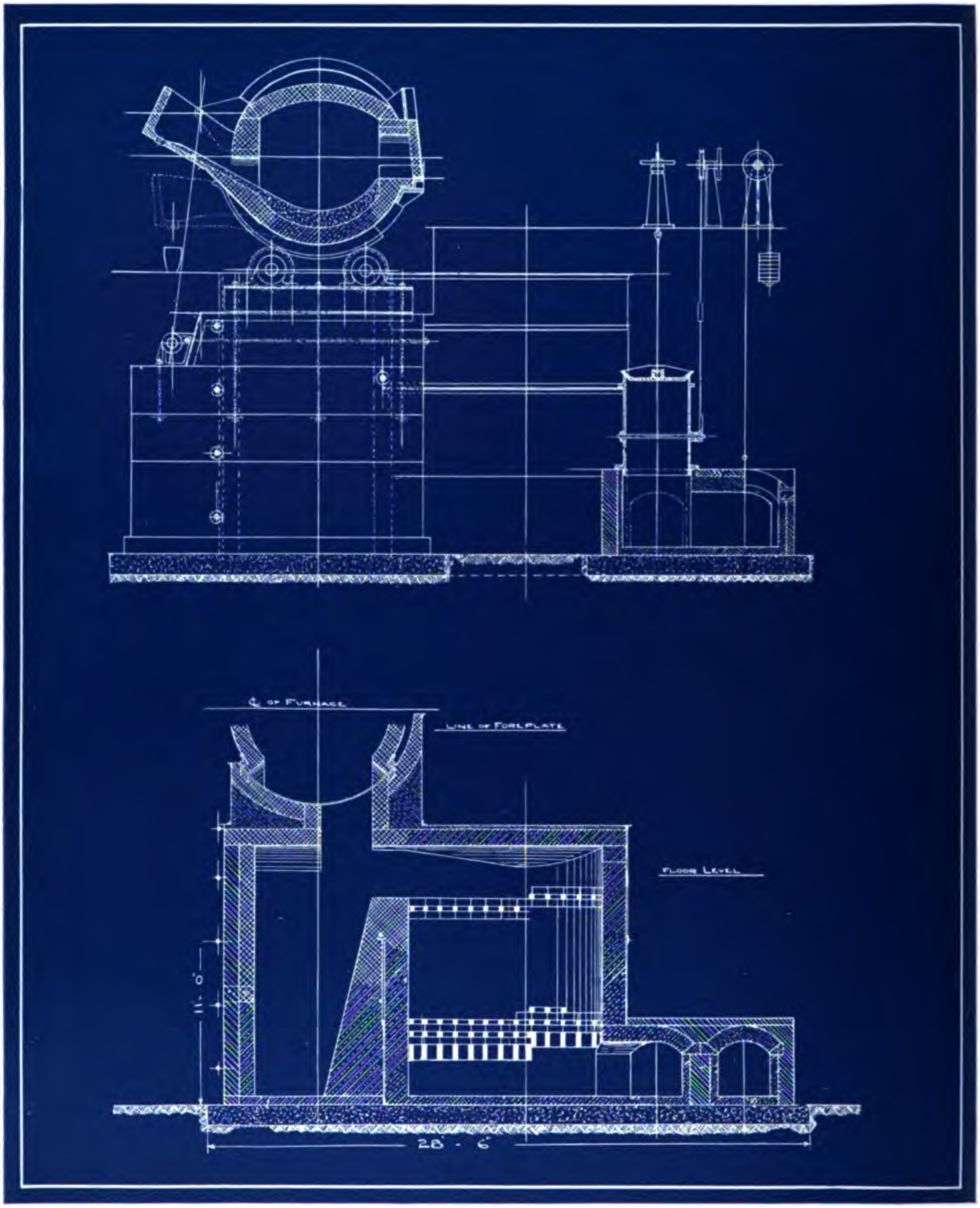


Figure 40—5-TON ACID TILTING WELLMAN OPEN HEARTH FURNACE

Installed at Firth Stirling Steel Company, McKeesport, Pa. The furnace is fitted with a fore hearth for pouring into crucibles. The port design and the water cooling at the joint between the stationary and tilting part of the uptakes shown.

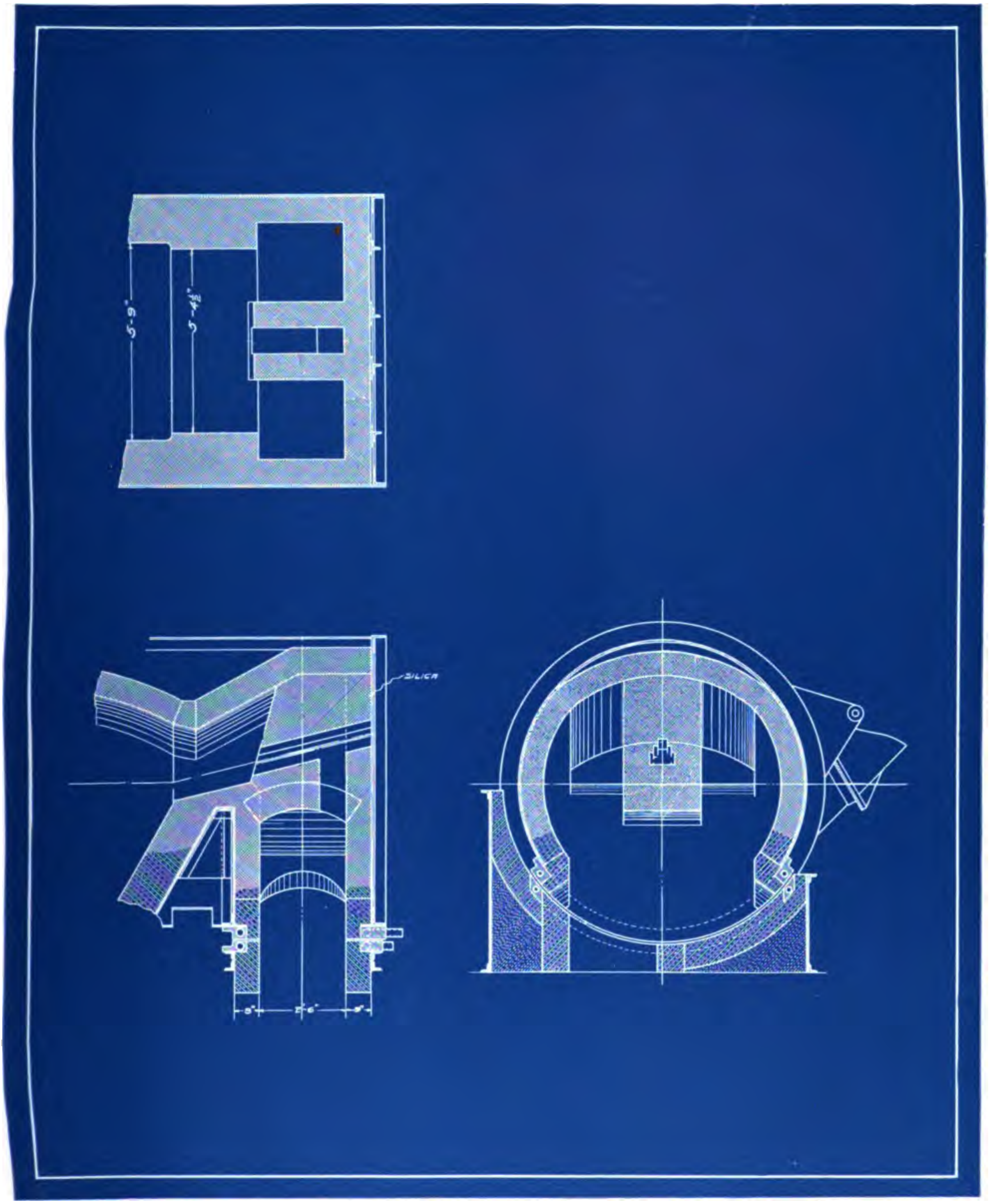


Figure 41—WATER COOLED JOINT BETWEEN PORT AND UPTAKE OF FURNACE SHOWN IN FIGURE 40

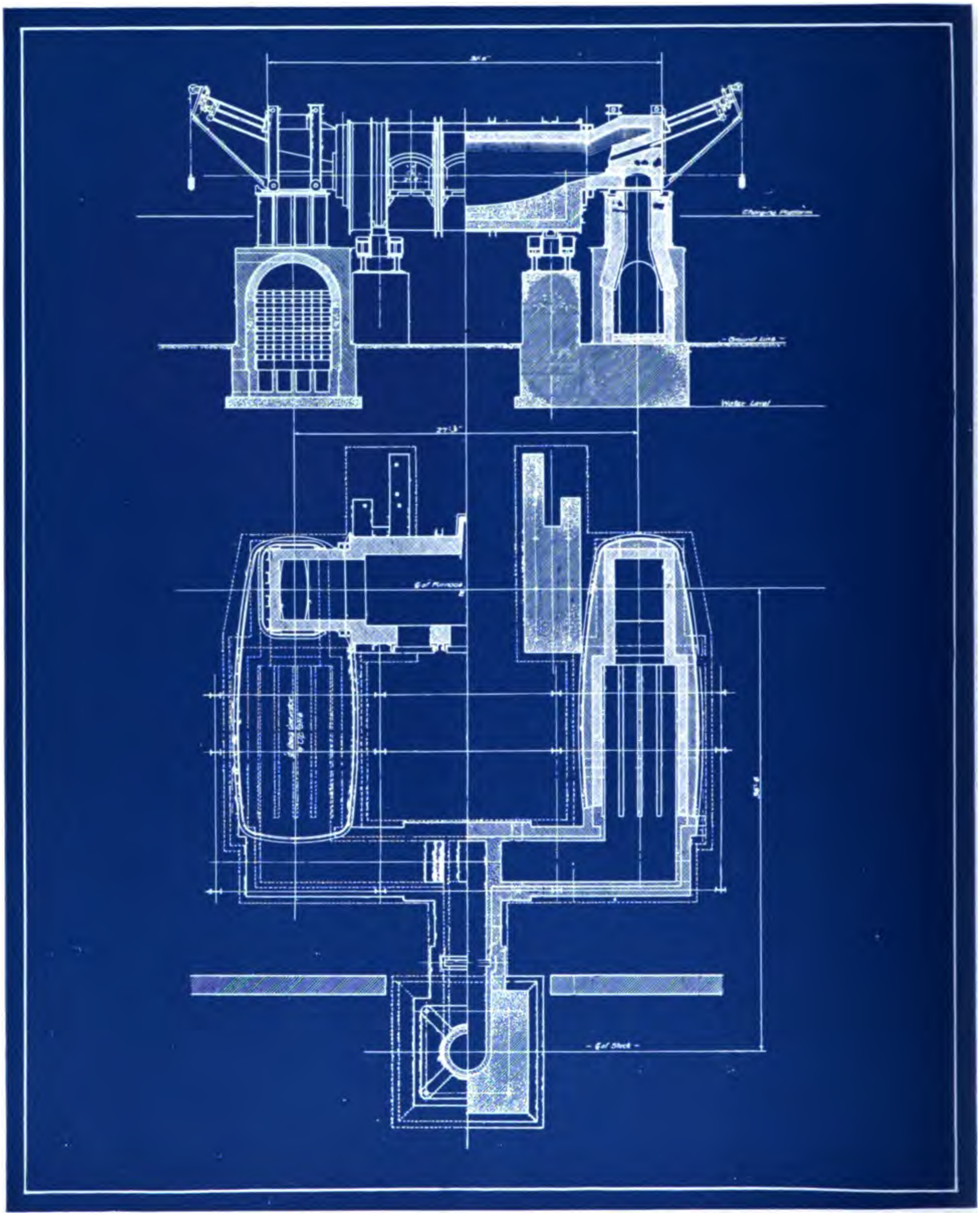
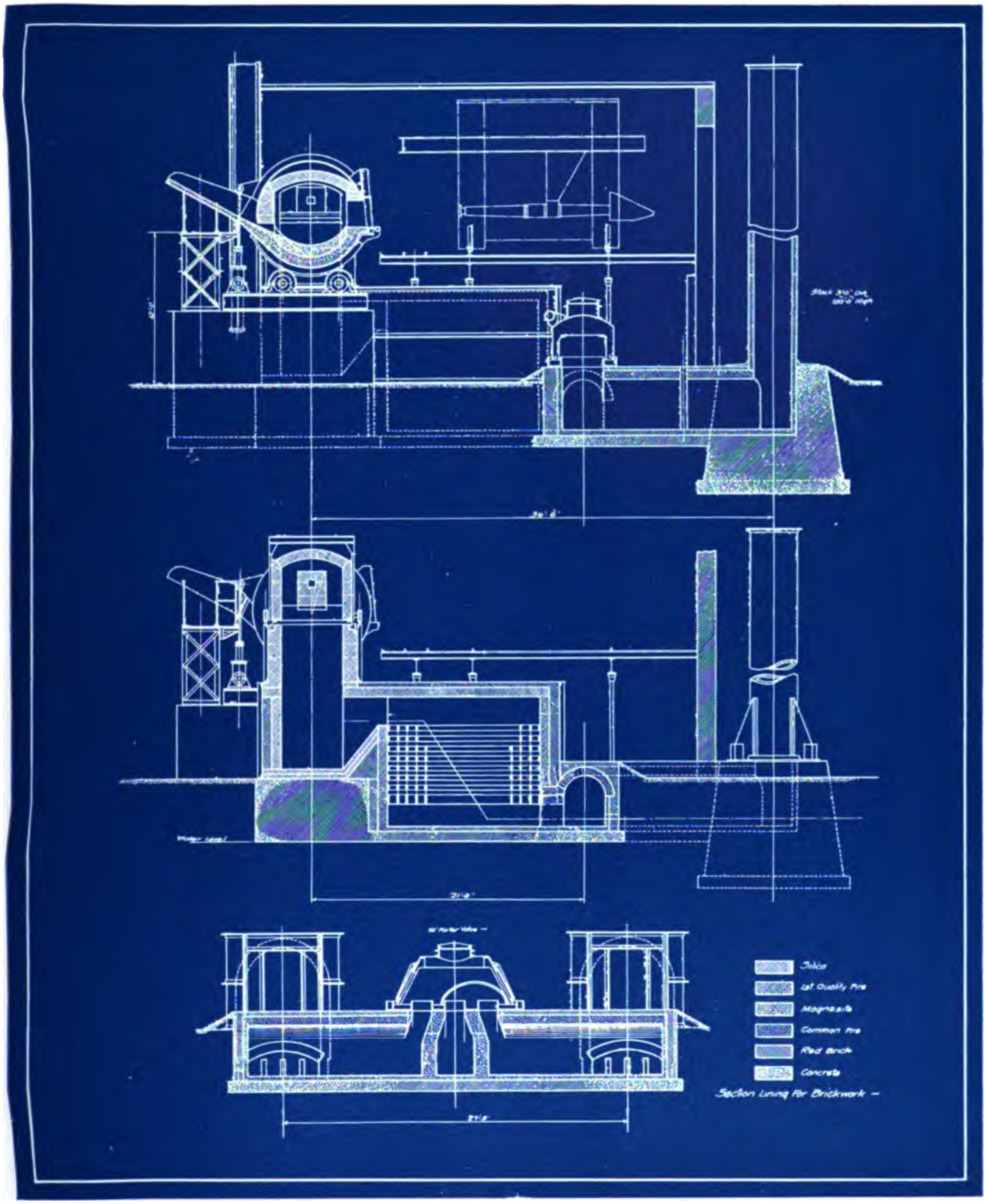


Figure 42—5-TON TILTING WELLMAN FURNACE

This furnace was built for the Prescott Company, Muskegon, Michigan. The furnace is hydraulic tilting. Oil is used for fuel. The hearth is 5 feet 9 inches by 16 feet. The area of the hearth is 92 square feet; area of the hearth per ton of steel being 18.4 square



feet. The ratio of the length to the width is 2.8. The regenerators are 6 feet 3 inches by 12 feet by 6 feet. The volume of the regenerator is 450 cubic feet, and the volume per ton of steel is 90 cubic feet. 30-inch valves are used. The stack is 3 feet net diameter and 100 feet high.

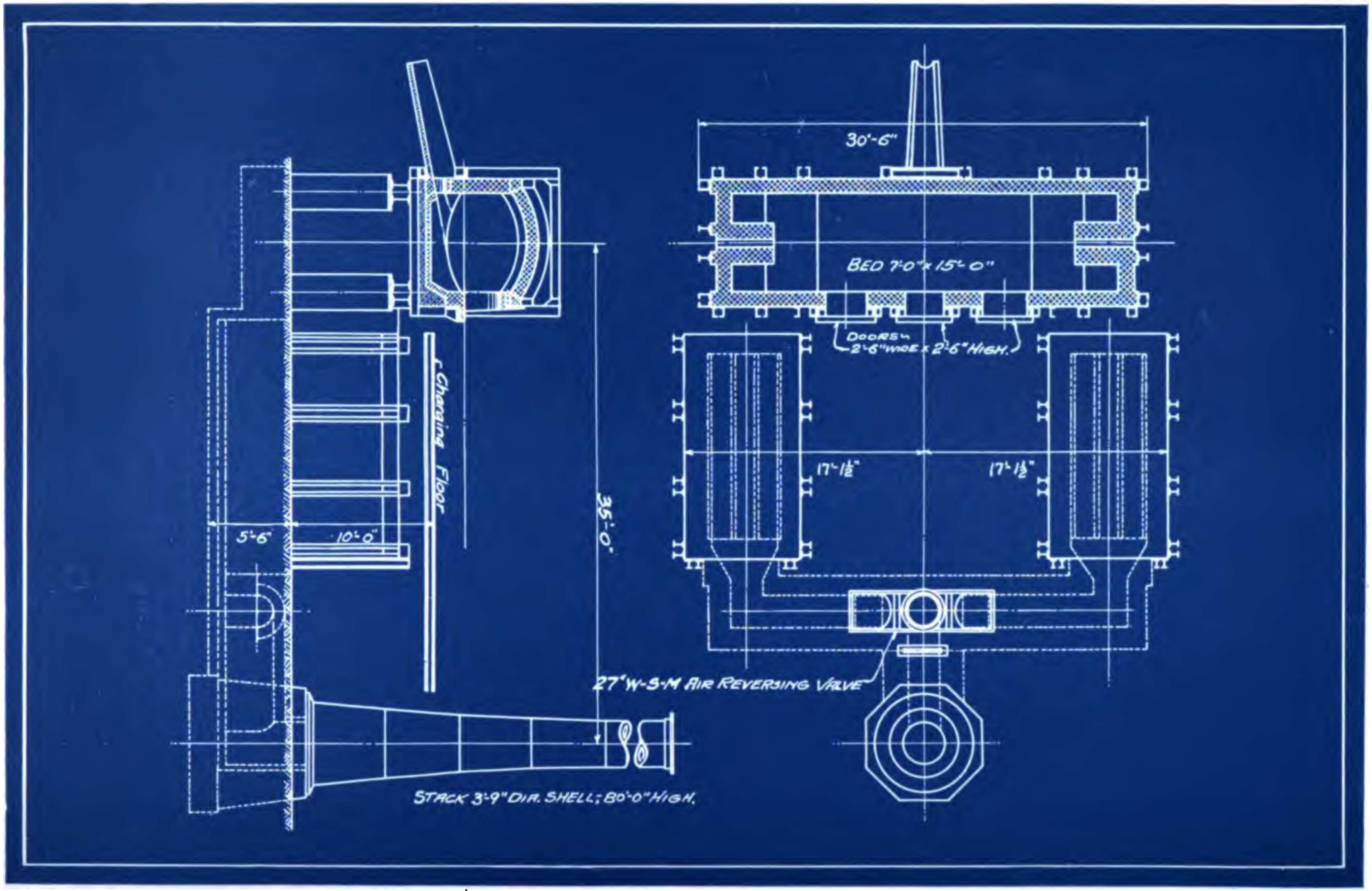

30'-6"
BED 7'-0" x 15'-0"
DOORS - 2'-6" WIDE x 2'-6" HIGH.
17'-1/2"
17'-1/2"
Charging Floor
35'-0"
5'-6"
10'-0"
27" W-S-M AIR REVERSING VALVE
STACK 3'-9" DIA. SHELL; 80'-0" HIGH.

Figure 43—7½-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Oil fuel. Hearth 7 feet by 15 feet by 1 foot 3 inches deep. Area 105 square feet. Area per ton of steel 14.0 square feet. Ratio length to width 2.1. 27-inch reversing air valve. Stack 3 feet net diameter by 80 feet high.

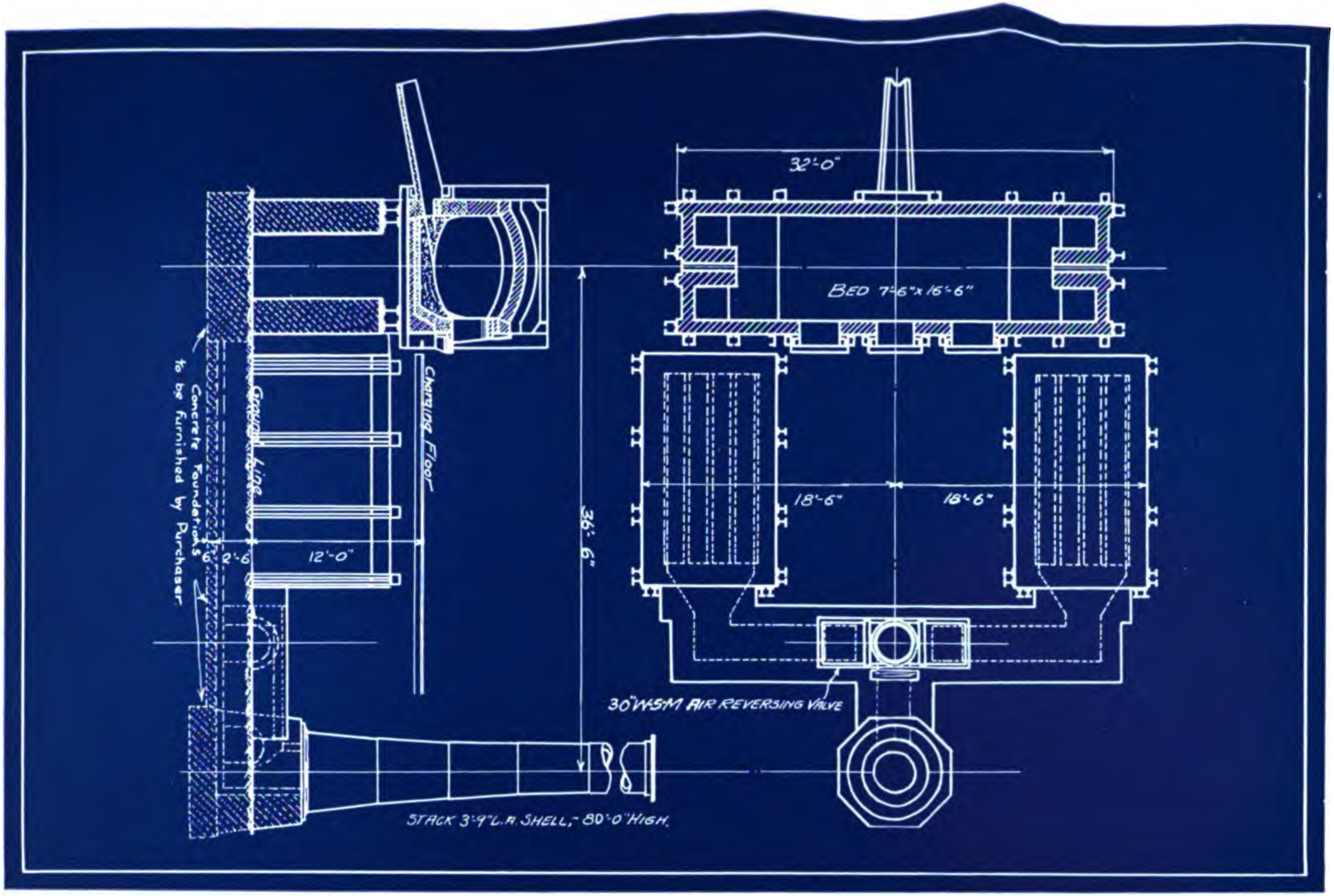


Figure 44—10-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Oil fuel. Hearth 7 feet 6 inches by 16 feet 6 inches by 1 foot 4 inches deep. Area 123.6 square feet. Area per ton of steel 12.4 square feet. 30-inch reversing air valve. Stack 3 feet net diameter by 80 feet high.

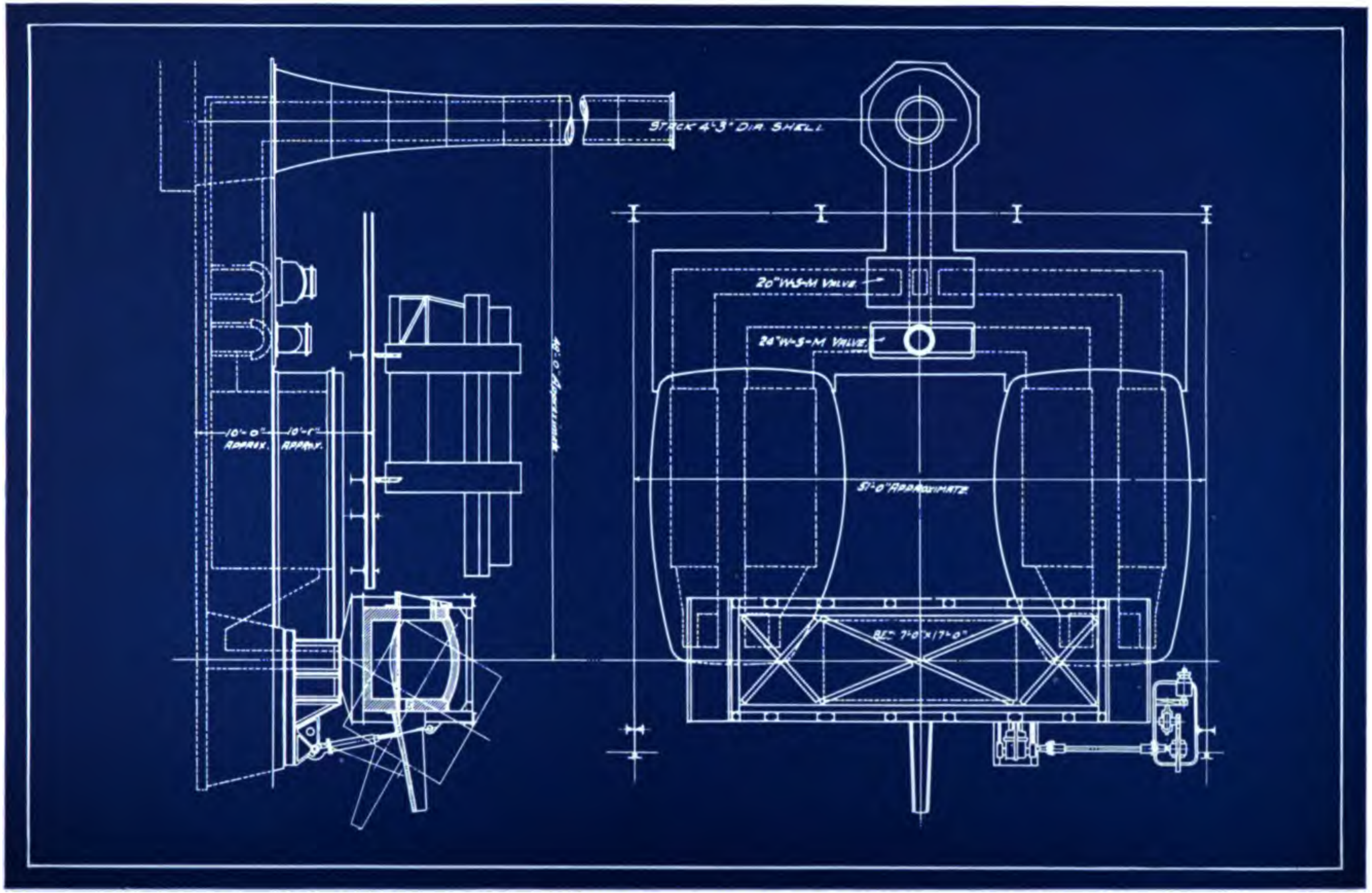


Figure 45—10-TON ACID TILTING WELLMAN OPEN HEARTH FURNACE

Hydraulic operation, producer gas fuel. Hearth 7 feet by 17 feet by 1 foot deep. Area 119 square feet. 20-inch gas, 24-inch air reversing valves. Regenerators 9 feet high, 17½ feet long, width gas 4 feet 8 inches, air 7 feet.

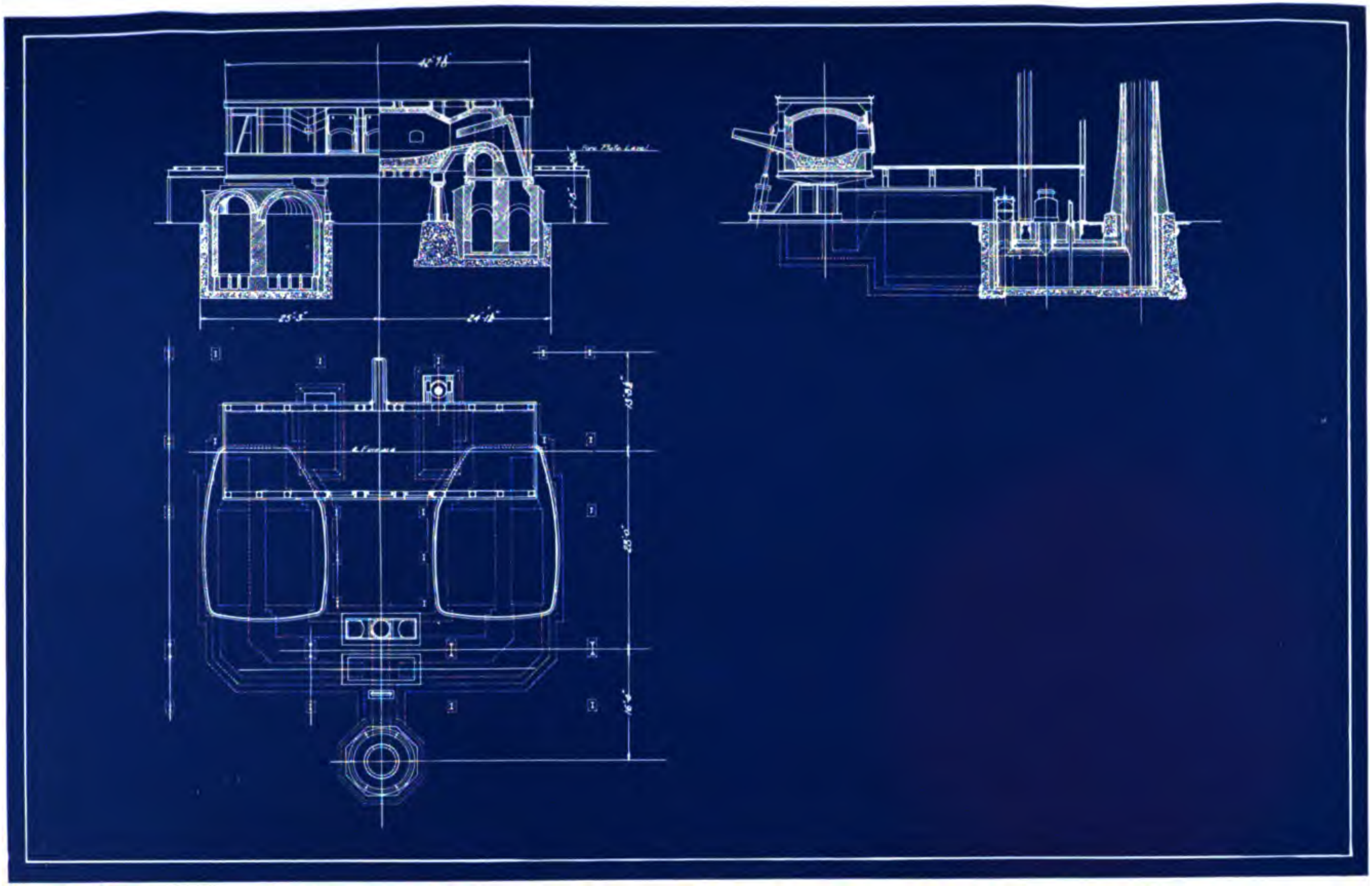


Figure 46—15-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

Hydraulic tilting. Producer gas fuel. Hearth 8 feet 9 inches by 20 feet 6 inches, 1 foot deep. Ratio of length to width 2.35. 24-inch gas, 27-inch air valves. Regenerators. Volume 1345 cubic feet, per ton 90 cubic feet.

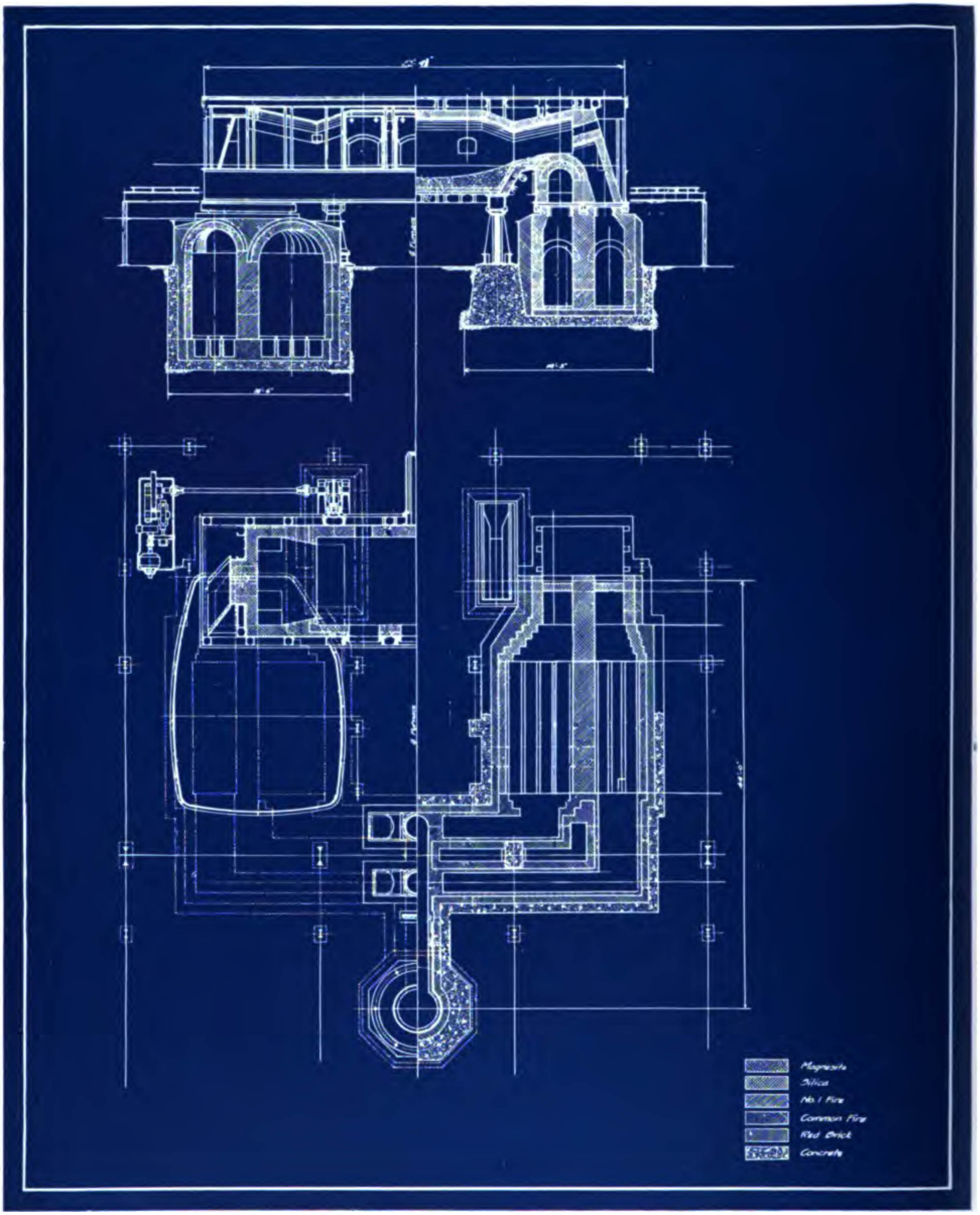
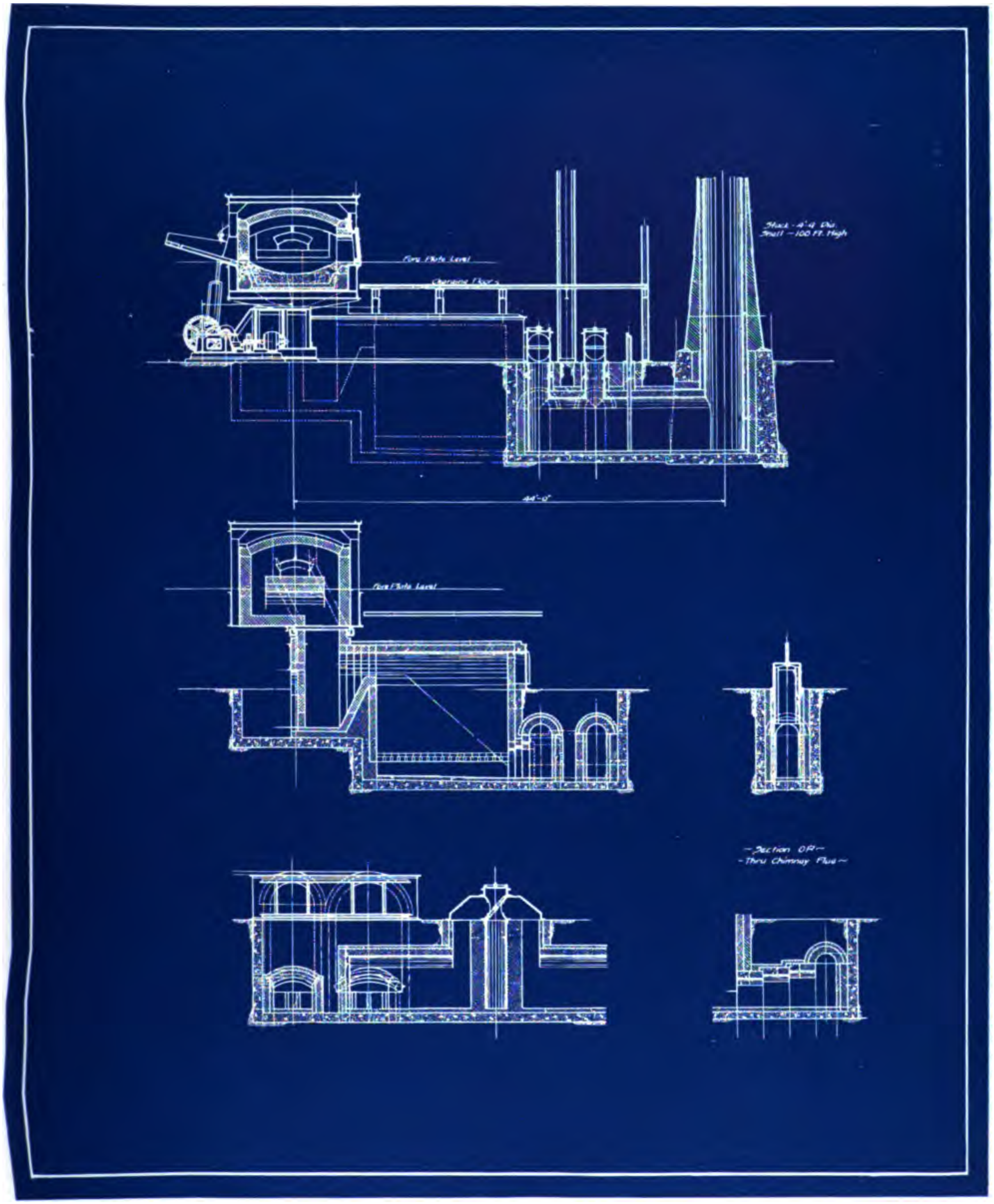


Figure 47—15-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

Installed at the Atlas Crucible Steel Company, Dunkirk, N. Y. Electric tilting. Producer gas or oil fuel. Hearth is 9 feet by 20 feet by 1 foot 3 inches deep. Area of hearth



is 180 square feet, and area per ton is 12.0 square feet. Ratio of length to width 2.22. 24-inch and 27-inch valves. Stack 4 feet net diameter, 100 feet high. Regenerators 8 feet 9 inches high, 13 feet 6 inches long; gas 4 feet 6 inches wide, air 6 feet 9 inches wide. Volume per ton is 98 cubic feet Ratio of air to gas is 1.5.

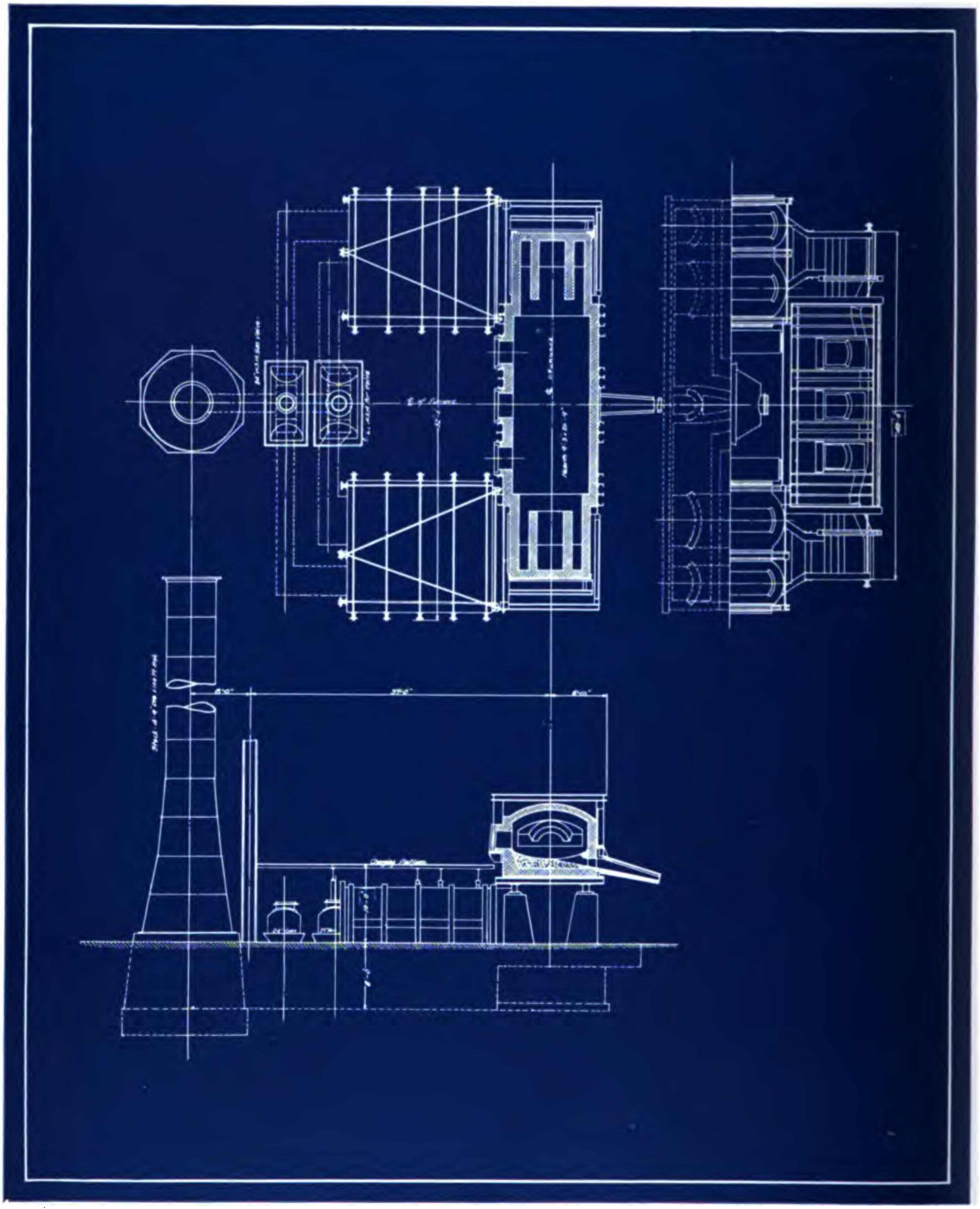


Figure 48—15-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Hearth 9 feet 3 inches by 20 feet 9 inches by 1 foot 3 inches deep. Area 192 square feet. Area per ton 12.8 square feet. Ratio of length to width 2.25. 24-inch gas, 27-inch air valves.

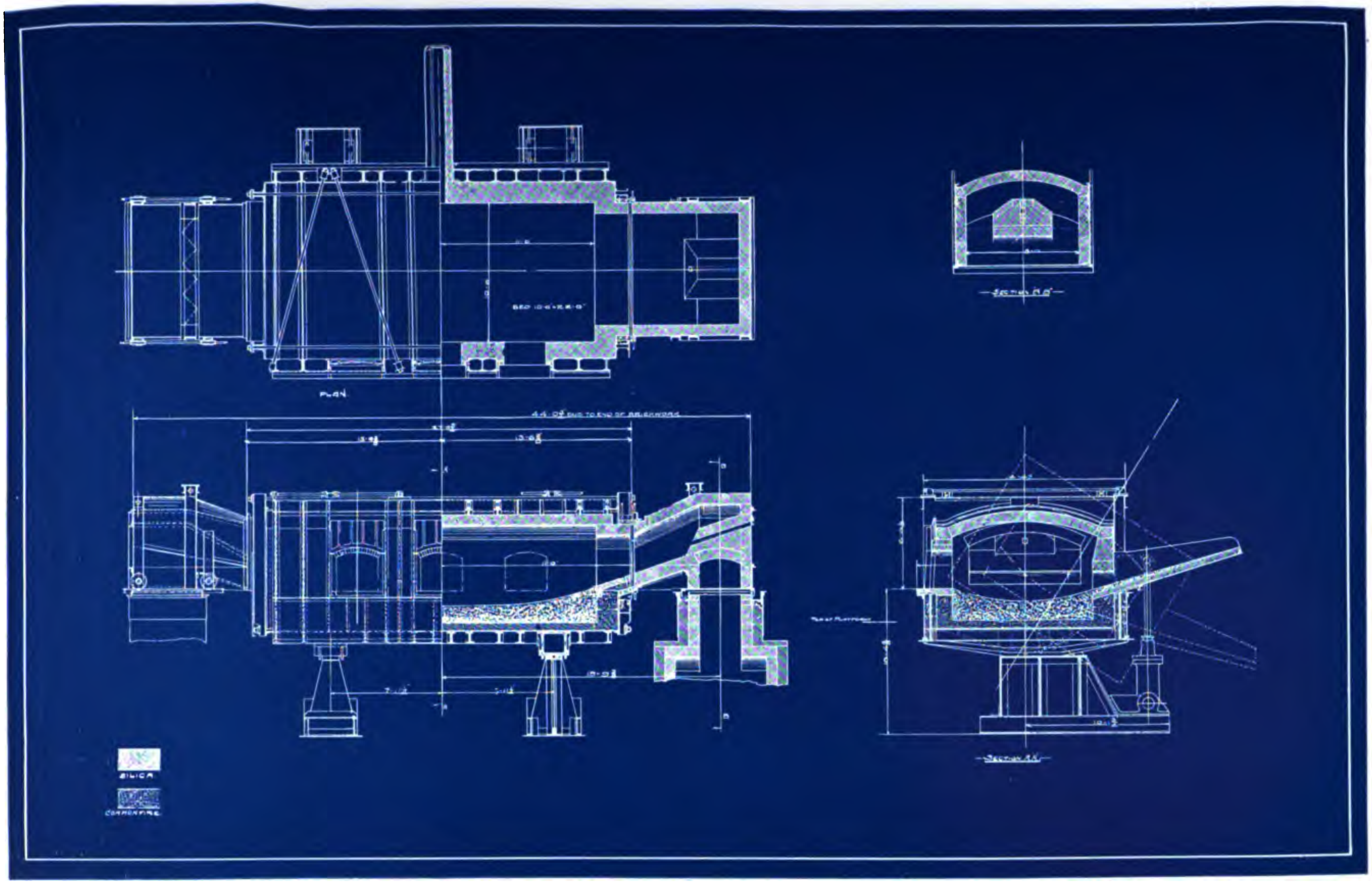


Figure 49—20-TON ACID TILTING WELLMAN OPEN HEARTH FURNACE

Built for Shickle Howard Harrison Company. Hydraulic tilting, oil fuel. Hearth 10 feet by 22 feet by 1 foot deep. Area 220 square feet. Ratio of length to width 2.2. Area per ton 11.0 square feet.

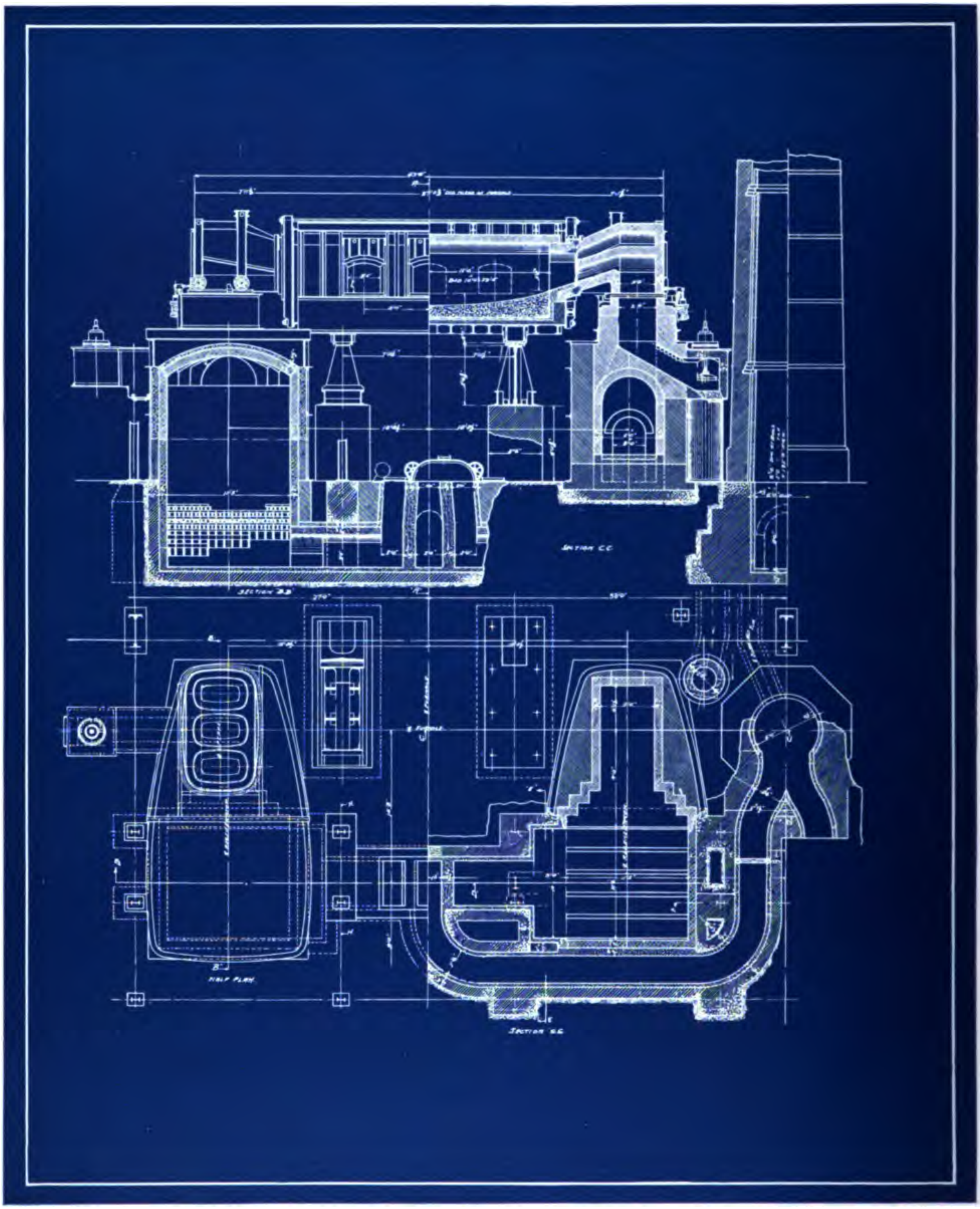
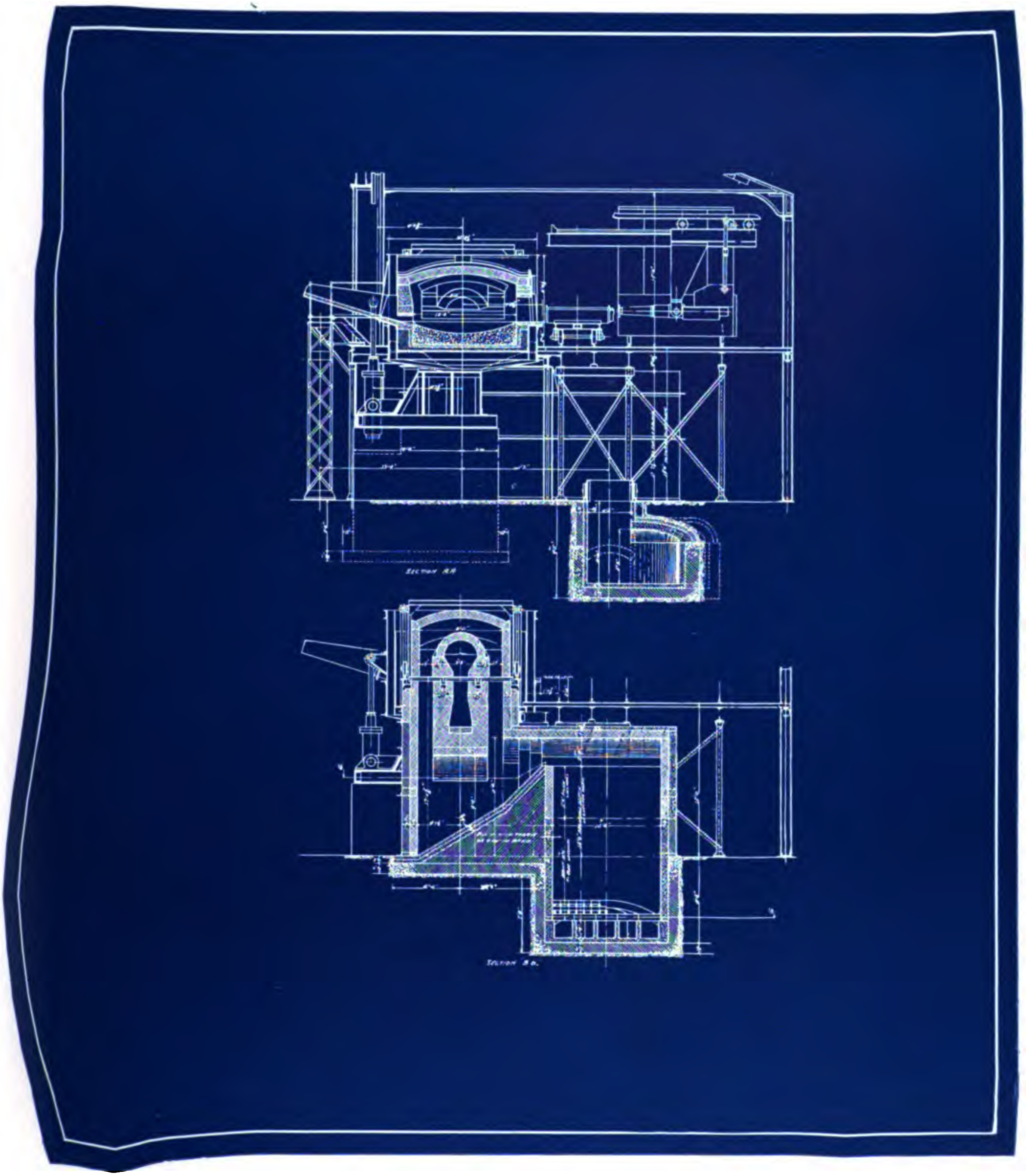


Figure 50—20-TON ACID TILTING WELLMAN OPEN HEARTH FURNACE

This furnace is hydraulic tilting. Oil is used for fuel. The hearth is 10 feet by 22 feet by 1 foot deep, the hearth area being 220 square feet and the area per ton 11.0 square



feet. The ratio of the length to the width is 2.2. The Custodis brick chimney is 125 feet high. The regenerators are 15 feet high, 10 feet 6 inches long and 10 feet 6 inches wide. The volume of the regenerators is 1654 cubic feet and the volume per ton of steel is 82.0 cubic feet.

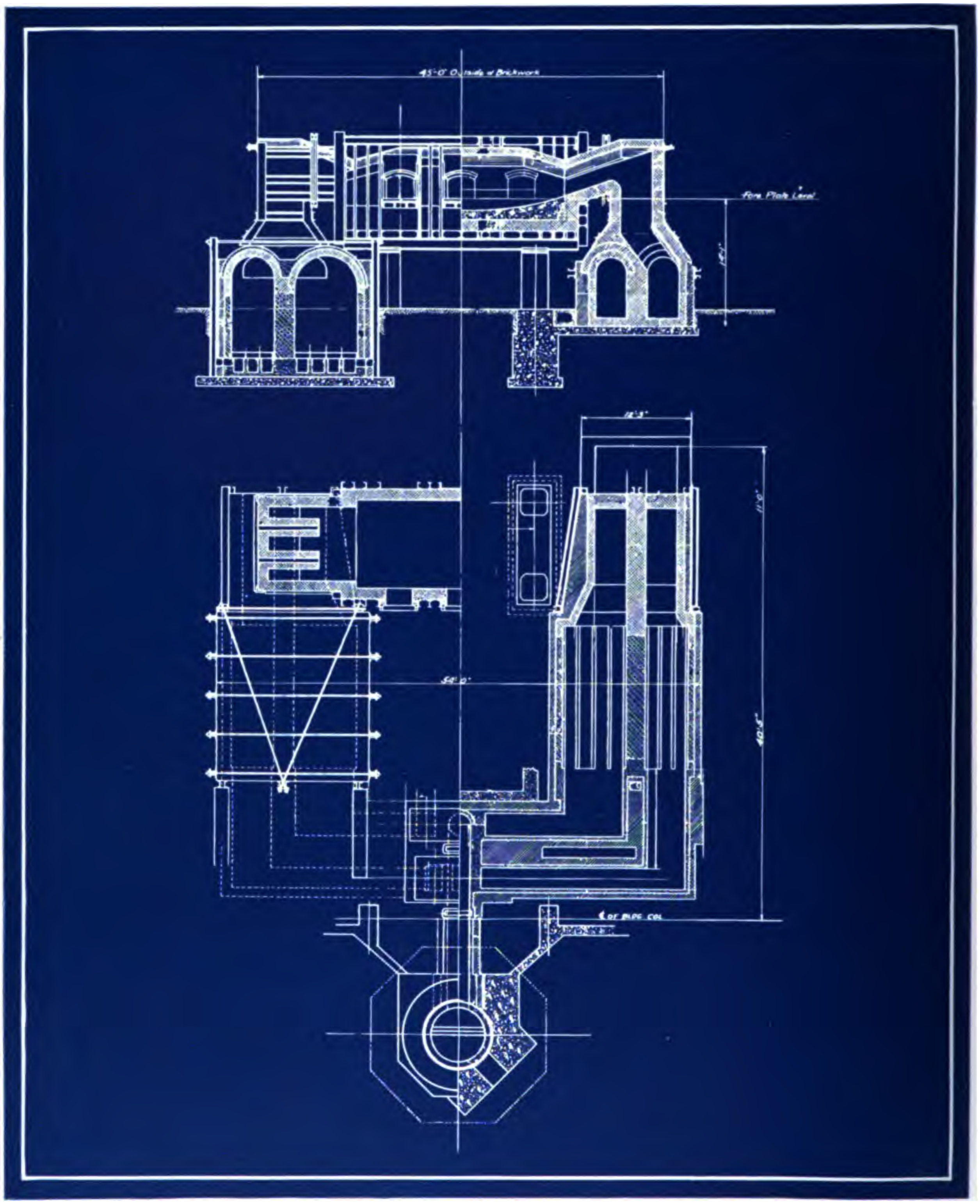
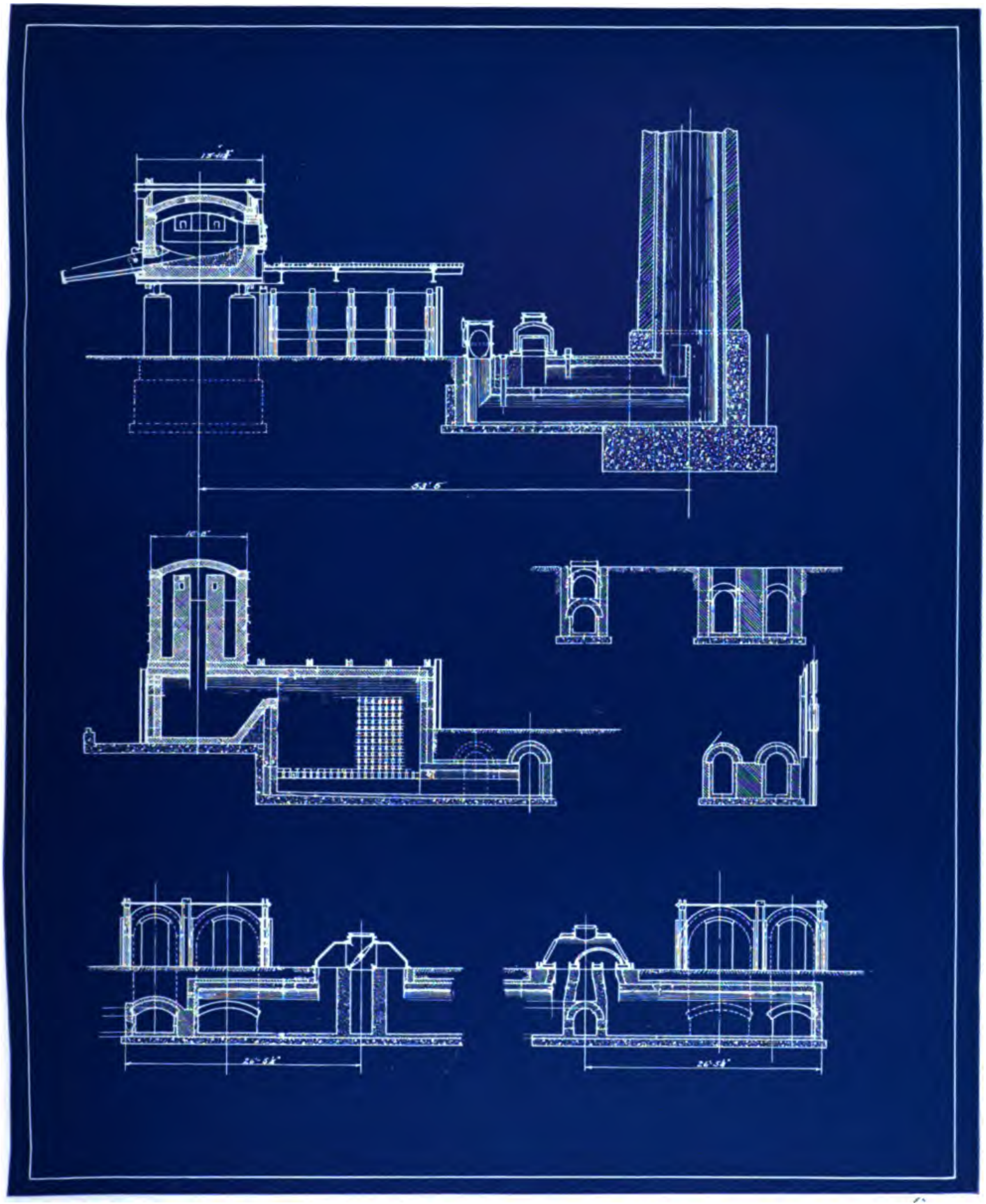


Figure 51—20-TON ACID STATIONARY OPEN HEARTH FURNACE

This 20 ton Wellman Open Hearth Furnace burns either fuel oil or producer gas. The hearth is 10 feet by 23 feet by 1 foot 3 inches deep. The area of the hearth is 230 square feet, the area per ton of steel being 11.5 square feet. The ratio of the length to



the width is 2.3. There is a 27-inch gas and a 30-inch air reversing valve. The stack is 4 feet 6 inches net diameter and 125 feet high. The regenerators are 9 feet high and 16 feet long. Gas 4 feet 9 inches wide, air 7 feet wide. The volume of the regenerator is 1692 cubic feet. Volume per ton is 84.6 cubic feet. The ratio of air to gas is 1.5.

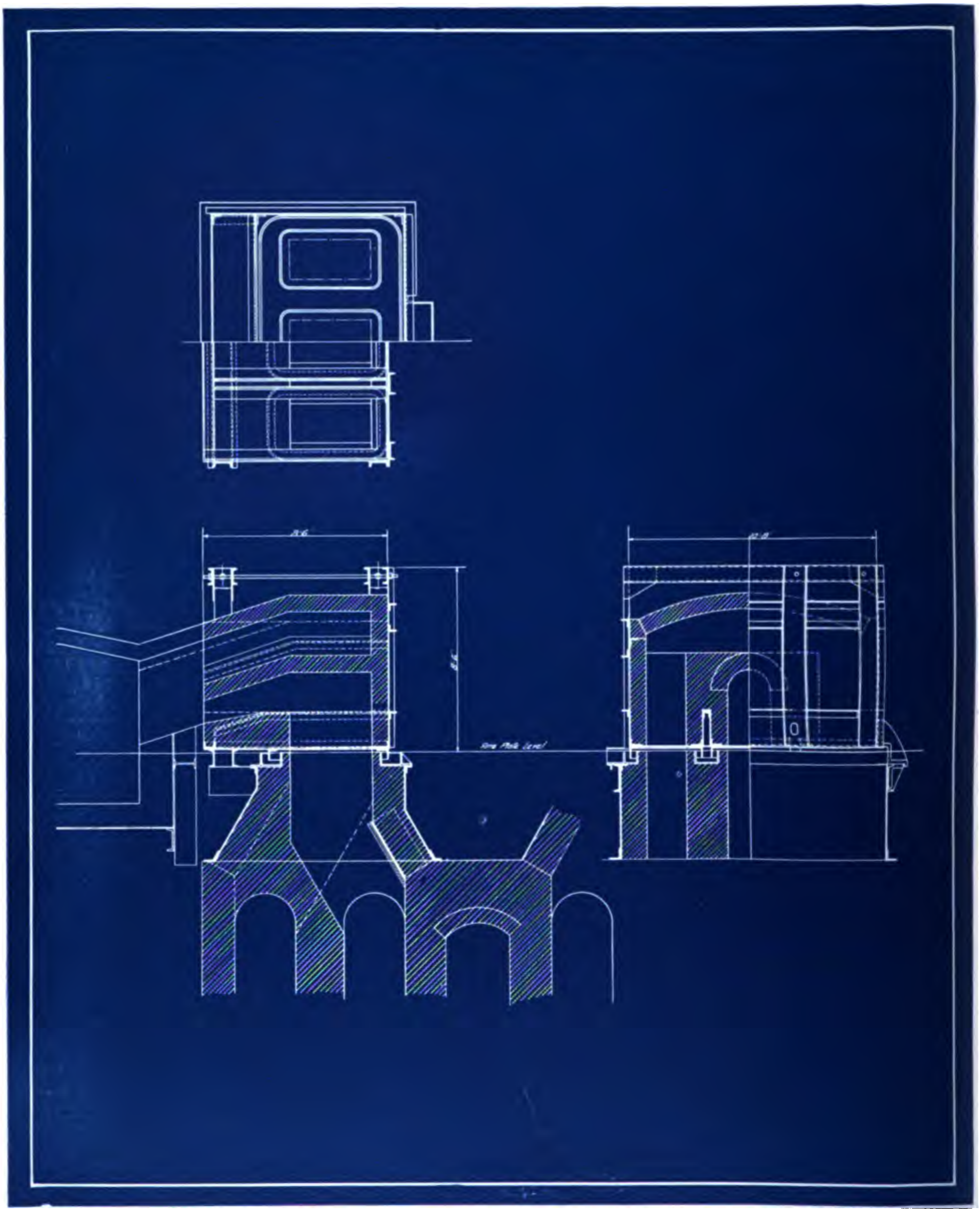


Figure 52—20-TON WELLMAN OPEN HEARTH FURNACE

This view shows the port end and lifting beam of a 20-ton Wellman Open Hearth Furnace.

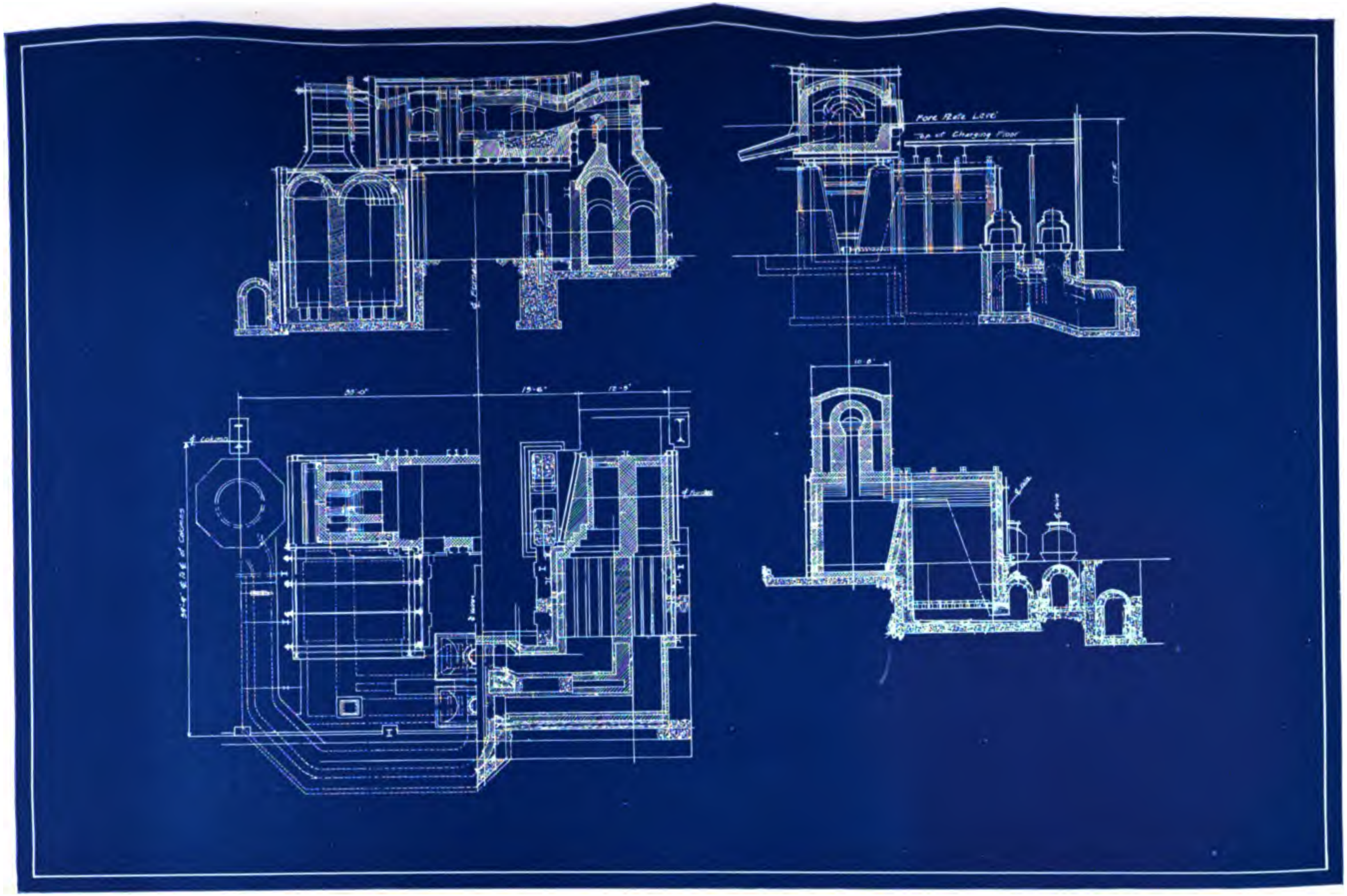


Figure 53—20-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Hearth 10 feet by 23 feet by 1 foot deep. Regenerators 14 feet 7 inches high, 10 feet long. Gas 4 feet 7 inches wide and air 6 feet 10 inches wide. Volume 1665 cubic feet. 27-inch gas and 30-inch air valves.

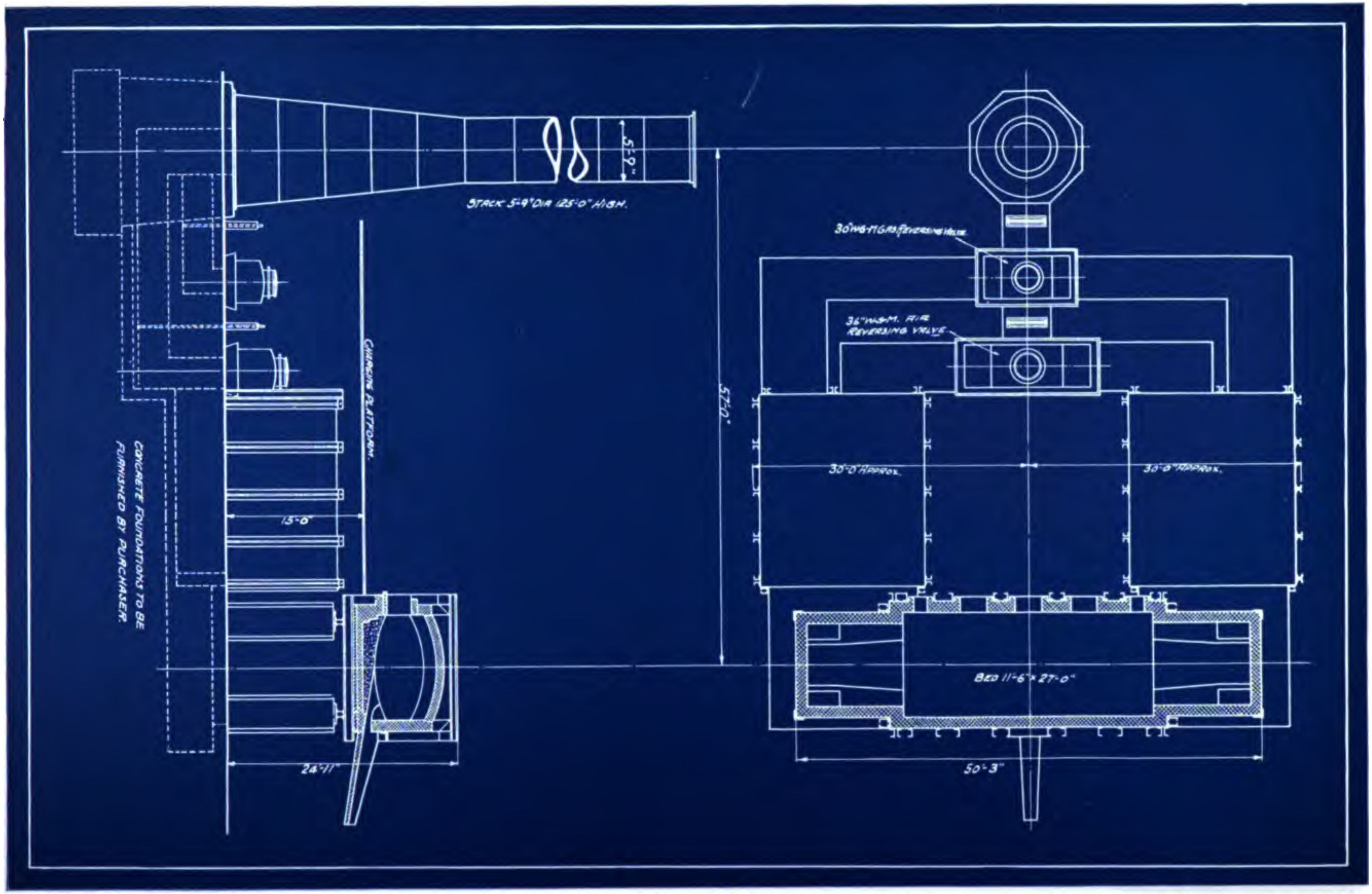

5'-9"
STACK 5'-9" DIA 125'-0" HIGH.
30" W-S-M GAS REVERSING VALVE
36" W-S-M. AIR REVERSING VALVE
57'-0"
30'-0" APPROX.
30'-0" APPROX.
BED 11'-6" x 27'-0"
50'-3"
CHARGING PLATFORM.
15'-0"
24'-11"
CONCRETE FOUNDATIONS TO BE FURNISHED BY PURCHASER.

Figure 54—30-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Hearth 11 feet 6 inches by 27 feet by 1 foot 3 inches deep. Hearth area 310 square feet. Area per ton 10.3 square feet. Ratio of length to width 2.4. 30-inch gas, 36-inch air valve.

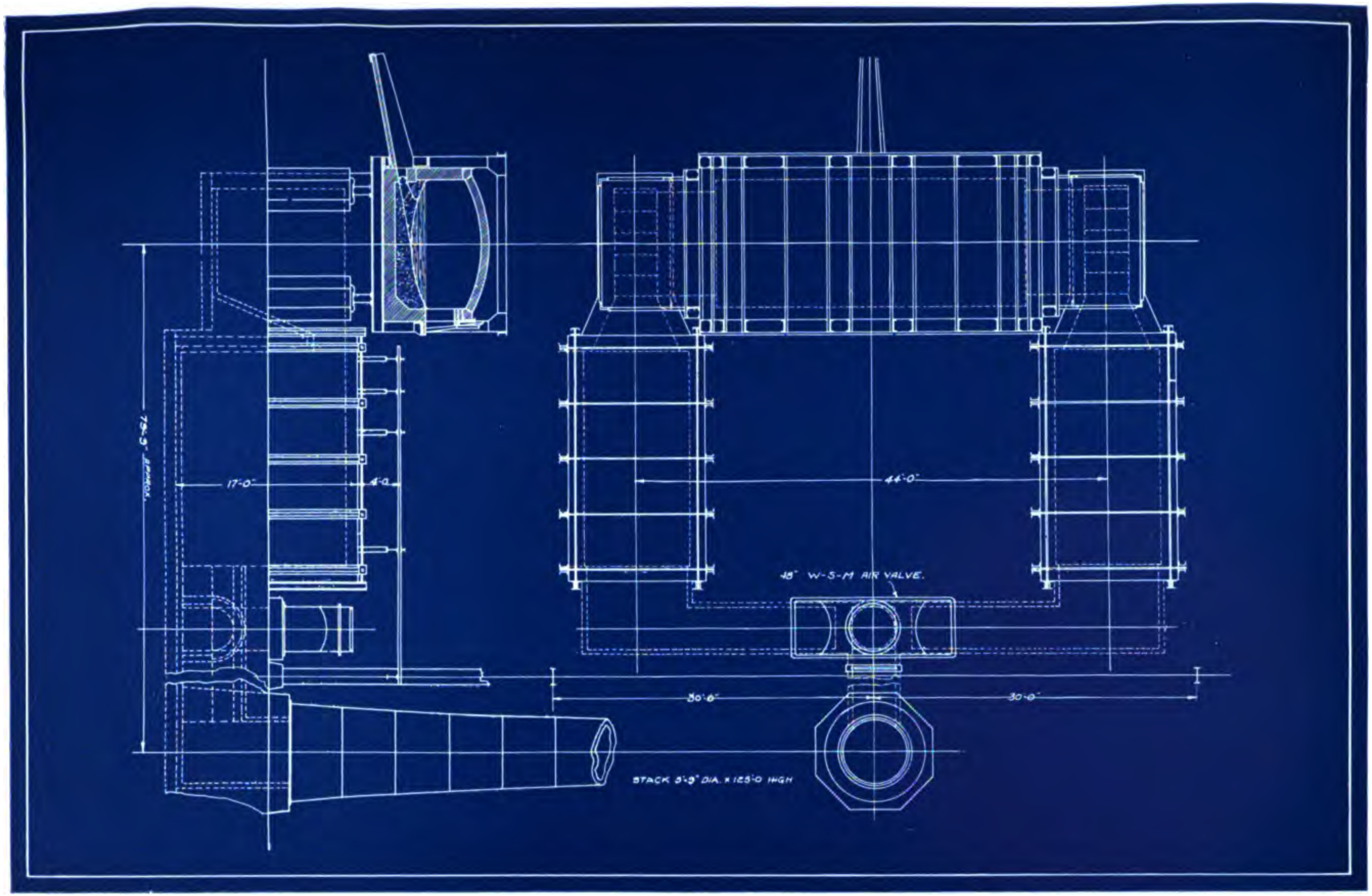


Figure 55—35-TON STATIONARY WELLMAN OPEN HEARTH FURNACE

Oil fuel. Hearth 12 feet by 29 feet by 5 inches deep. Area 348 square feet. Area per ton 10 square feet. Ratio of length to width 2.45. 48-inch air valve. Stack 5 feet net diameter by 125 feet high.

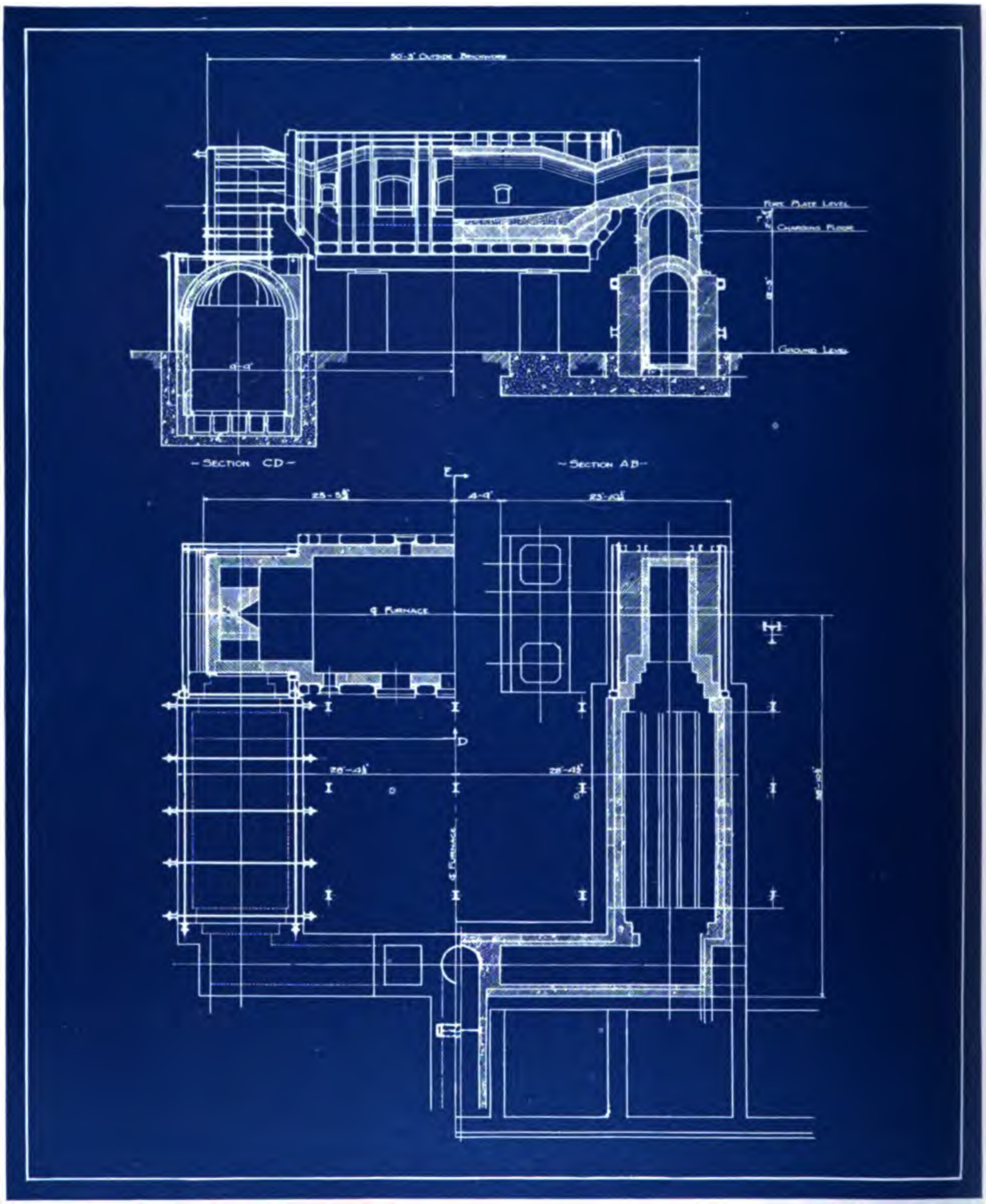
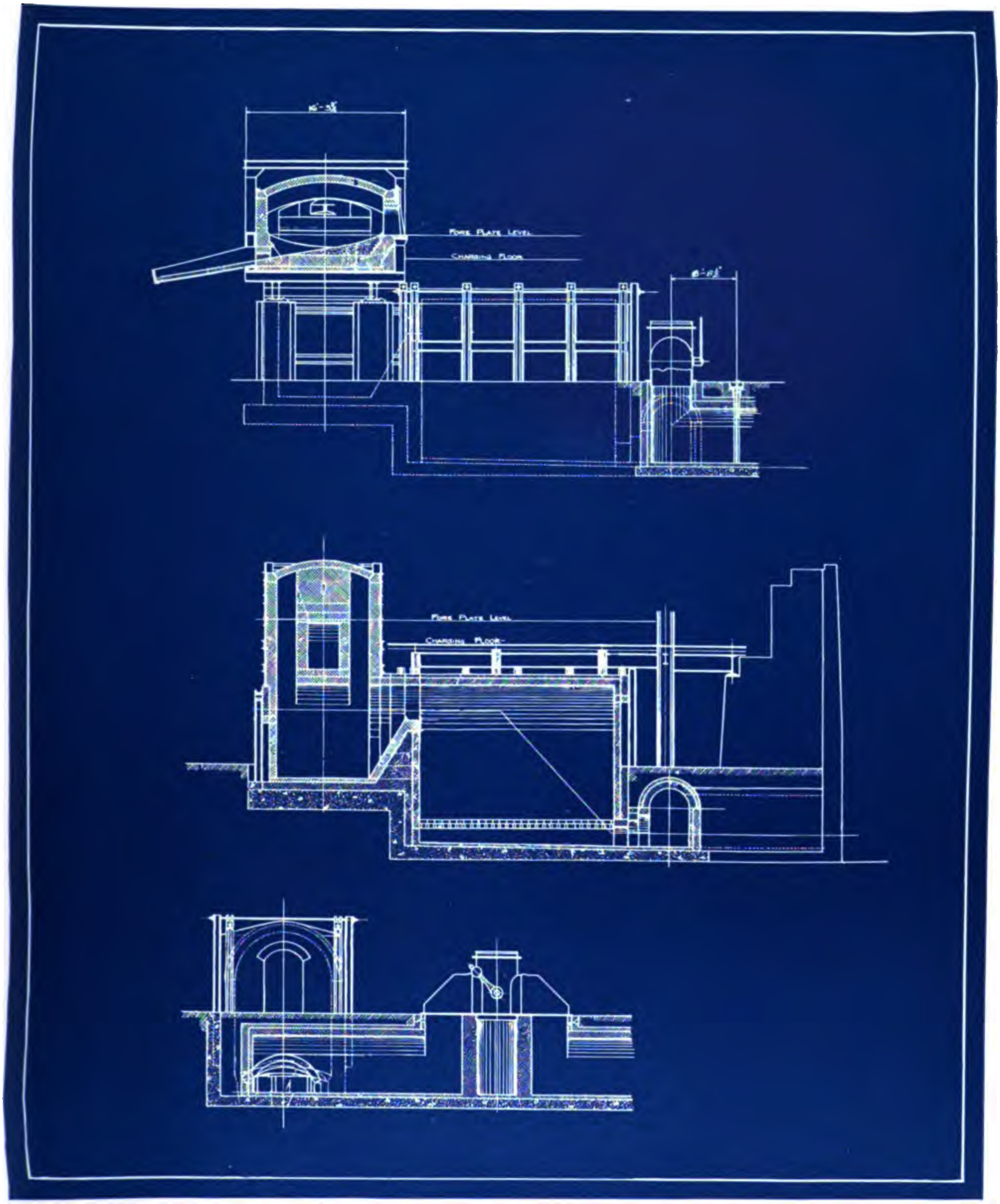


Figure 56—35-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Built for the U. S. Army at the Watertown Arsenal, Watertown, Mass. Oil fuel. Hearth 12 feet by 29 feet by 1 foot 3 inches deep. Area 348 square feet. Area per ton



10.0 square feet. Ratio of length to width 2.42. 48-inch valve. Regenerator 11 feet 2½ inches by 20 feet long, 9 feet 9 inches wide. Volume 2184 cubic feet. Volume per ton 62.2 cubic feet.

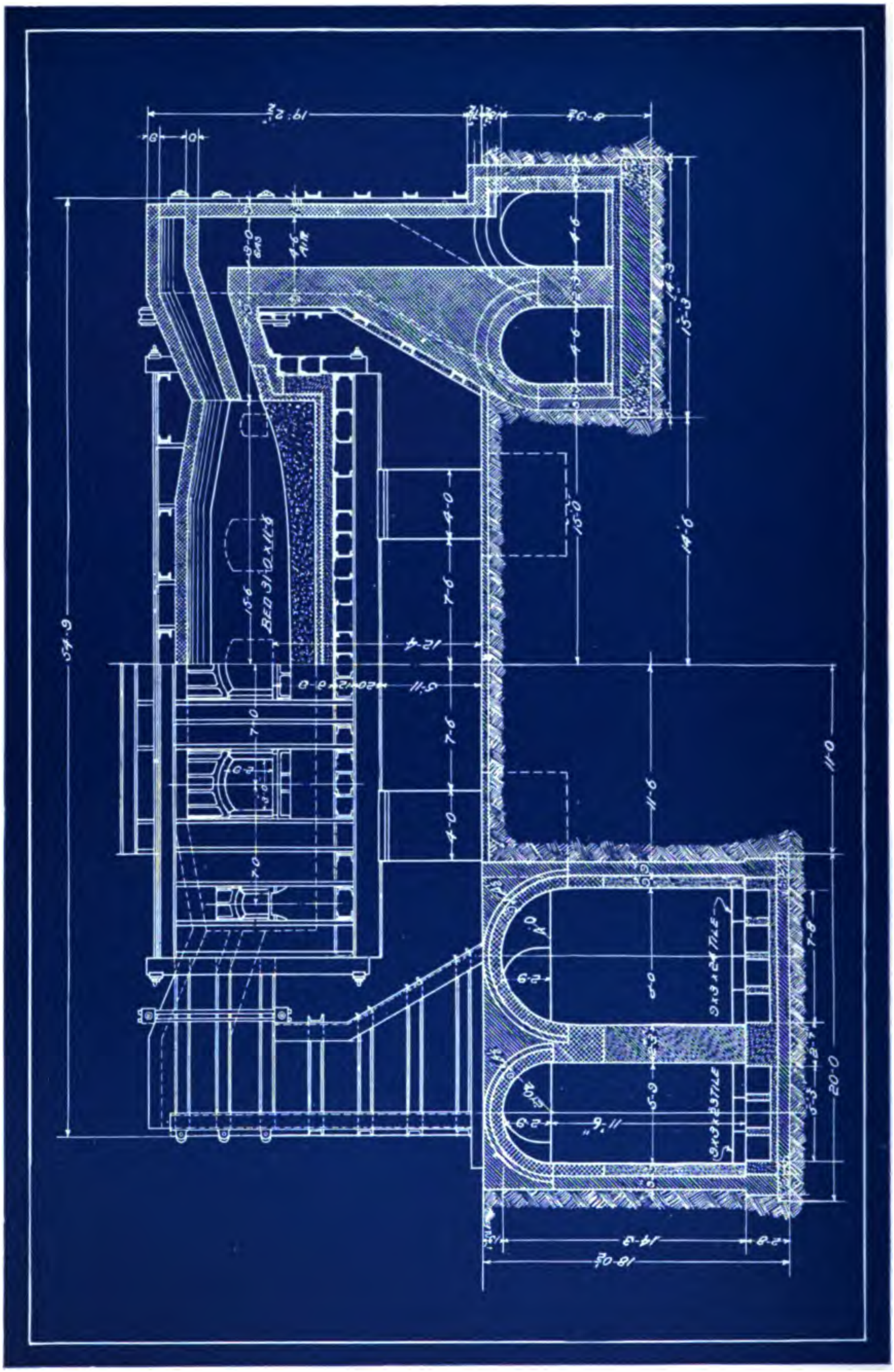


Figure 57—35-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Hearth 11 feet 6 inches by 31 feet by 1 foot deep. Ratio of length to width 2.7. 32-inch gas valve, 32-inch air valve. Stack 5 feet net diameter and 135 feet high.

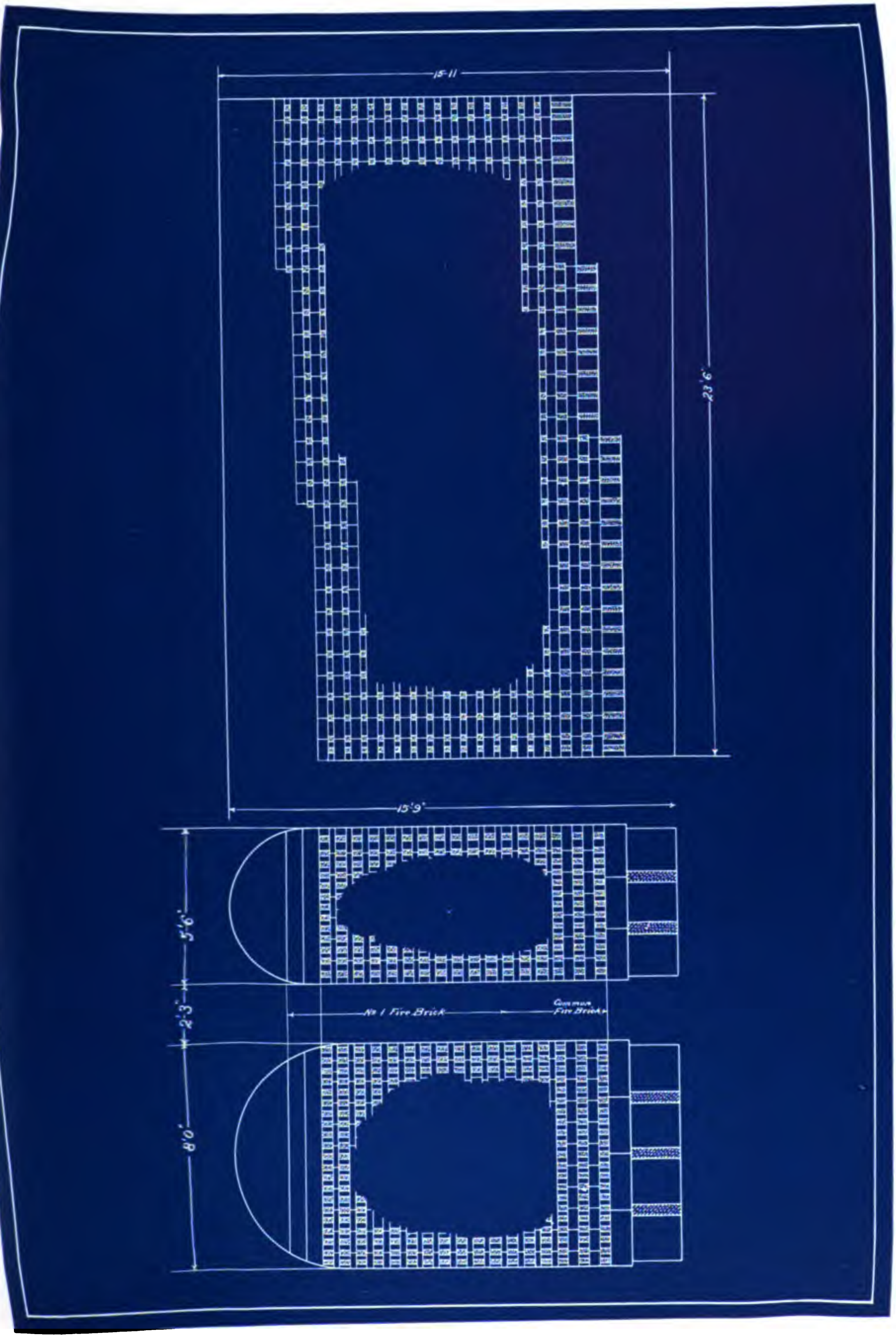


Figure 58—ARRANGEMENT OF CHECKER BRICK IN 50-TON OPEN HEARTH FURNACE REGENERATORS

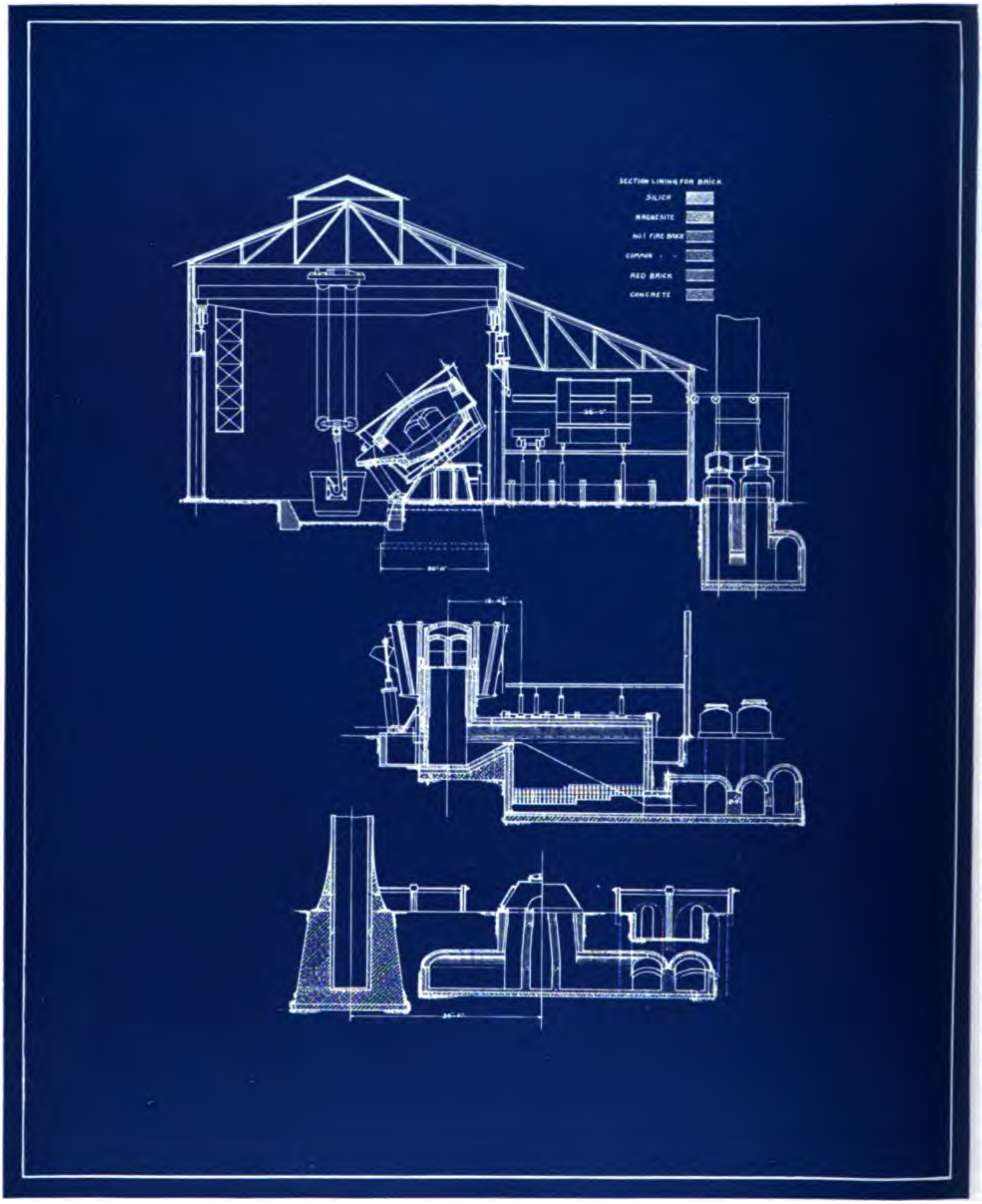
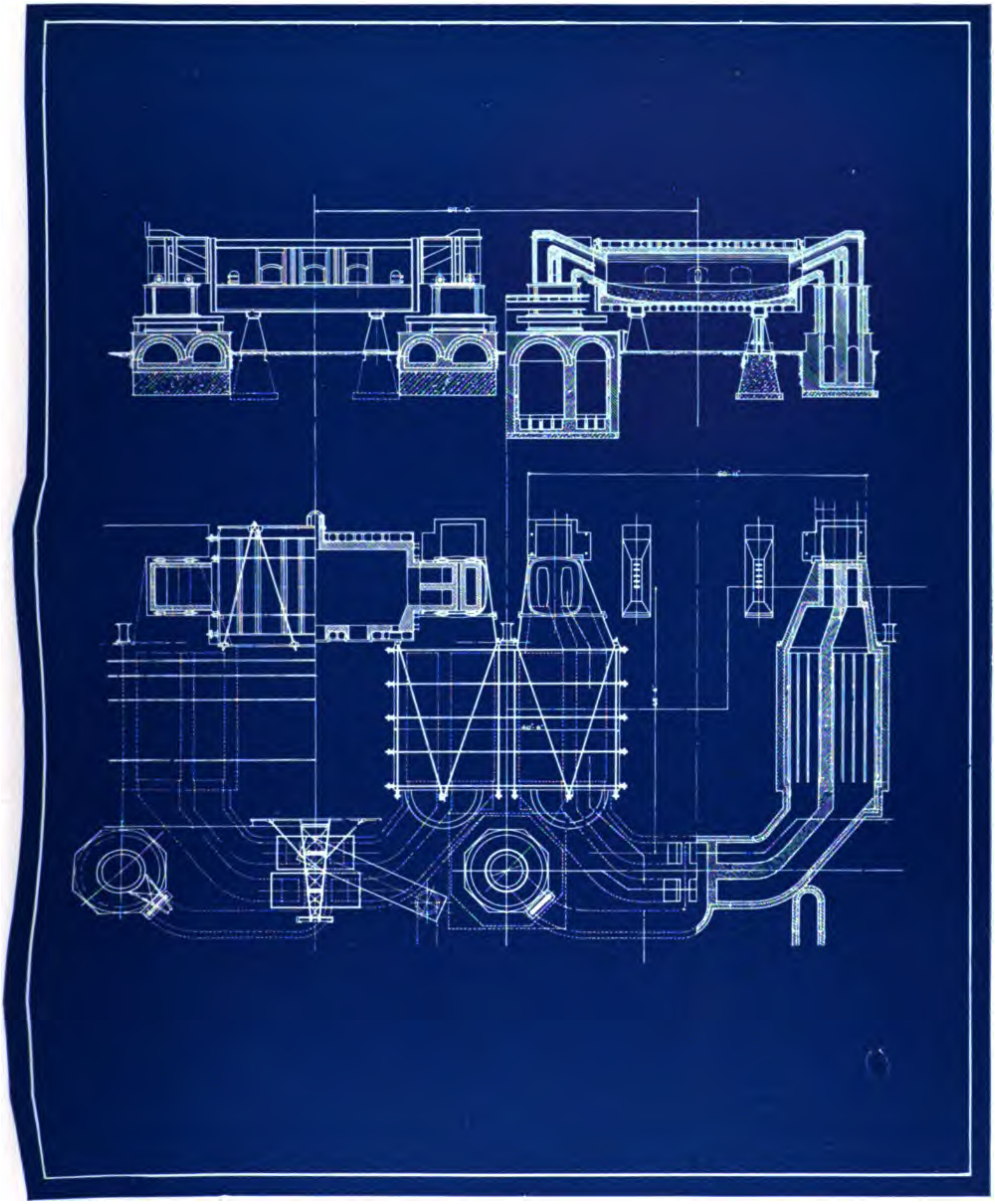


Figure 59—50-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

One of two furnaces built for Imperial Japanese Government in its Kure Arsenal. Producer gas is used for fuel. Hydraulic tilting. The hearth is 13 feet by 33 feet by 1 foot 4 inches deep. The area is 429 square feet, the area per ton being 8.6 square feet.



The ratio of the length to the width is 2.54. There is a 42-inch gas and a 48-inch air reversing valve. The stack is 6 feet in net diameter and 150 feet high. The regenerator is 13 feet 6 inches high, 23 feet 6 inches long and 5 feet 6 inches wide for gas and 8 feet wide for air. Volume is 4100 cubic feet. The volume per ton is 82.0 cubic feet.

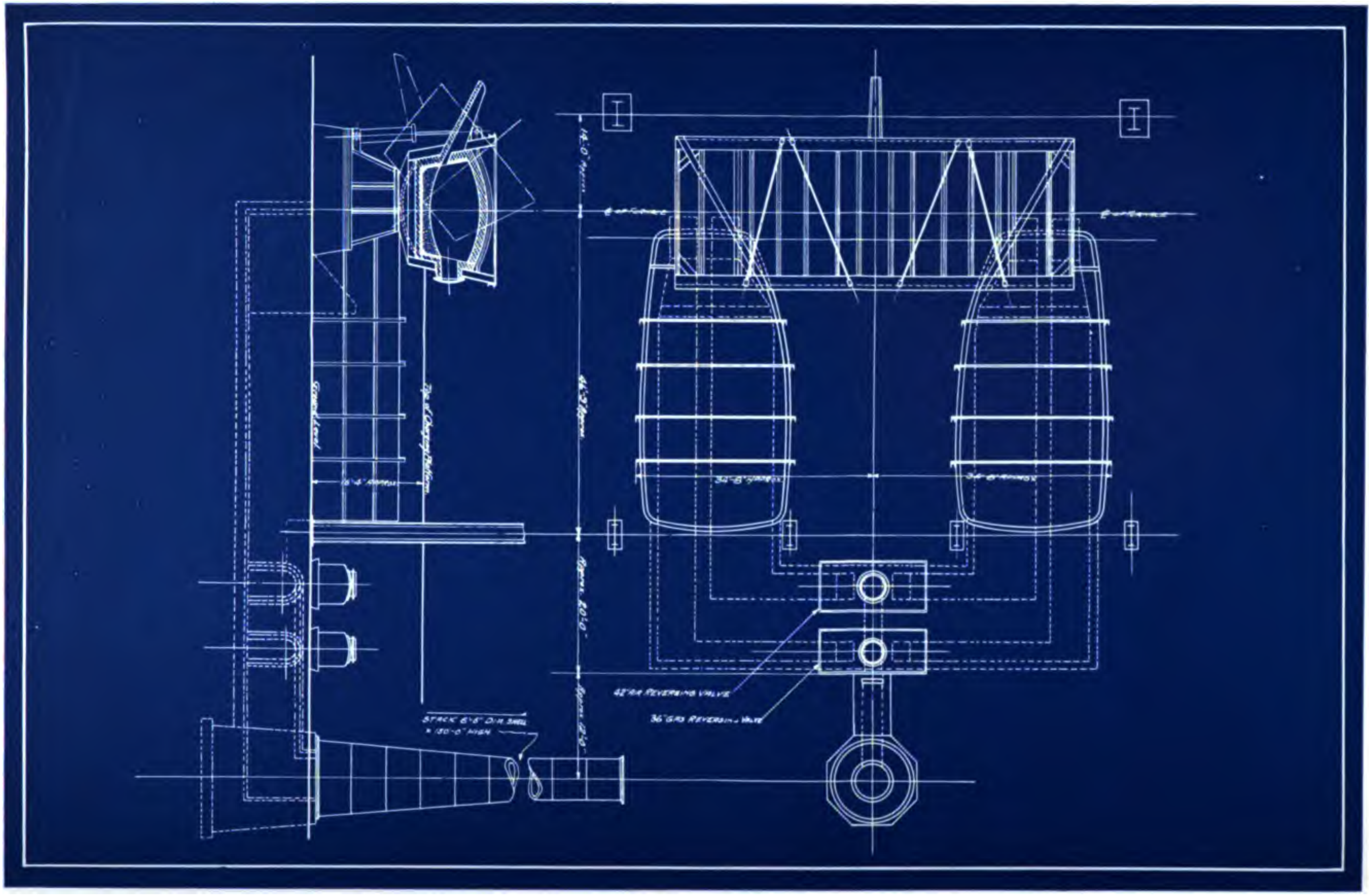


Figure 60—50-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

Hydraulic tilting. Producer gas fuel. Hearth 13 feet by 33 feet by 1 foot 4 inches deep. Area 429 square feet. Ratio length to width 2.5. 36-inch gas, 42-inch air valves. Stack 5 feet 9 inches net diameter, 150 feet high.

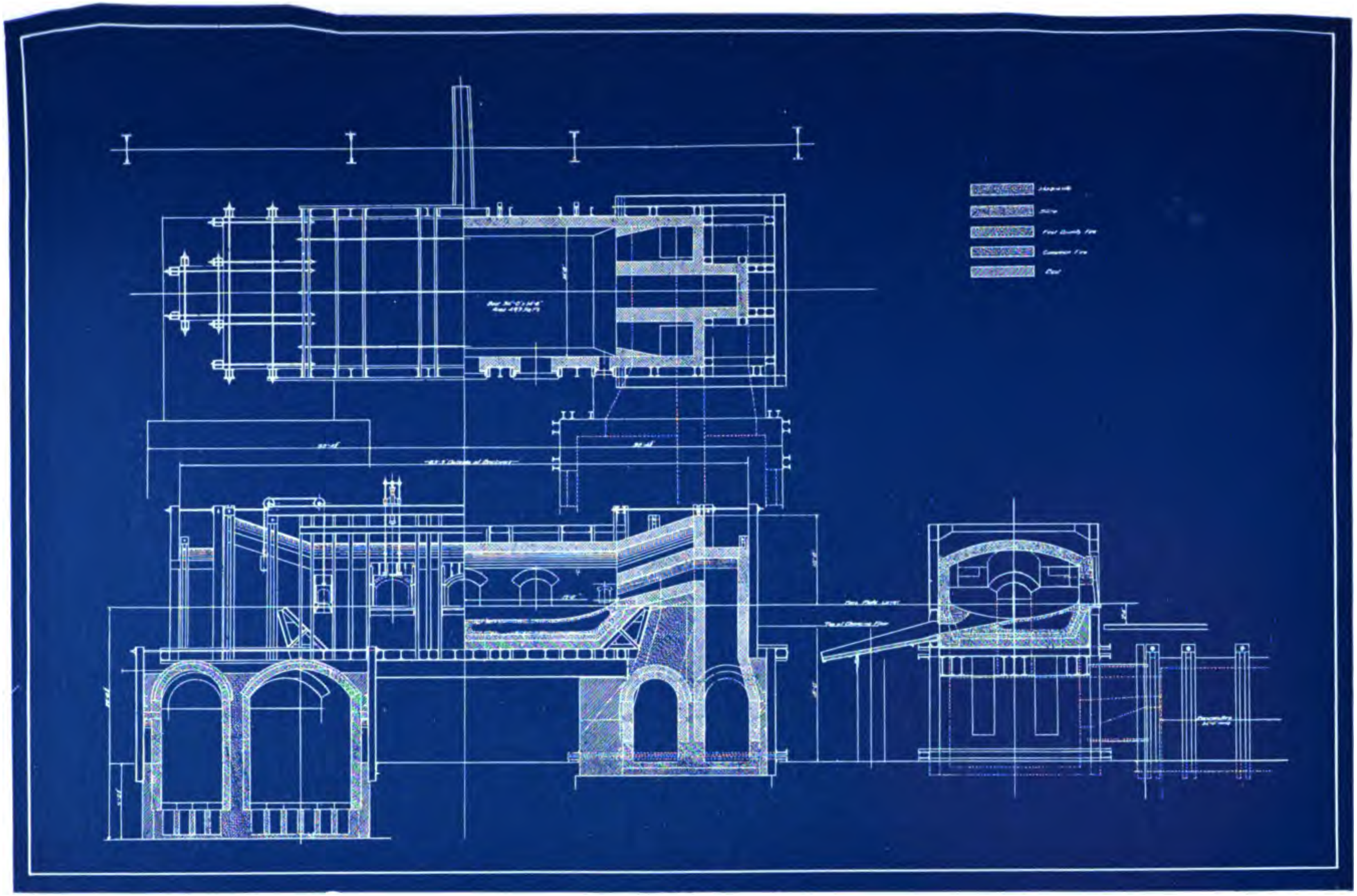


Figure 61—60-TON STATIONARY WELLMAN OPEN HEARTH FURNACE

Hydraulic door lifting. Producer gas fuel. Hearth 14 feet 6 inches by 34 feet by 1 foot 10 inches deep. Regenerators 11 feet 3 inches high, 24 feet long. Gas 6 feet 9 inches wide, air 11 feet 3 inches wide. Volume 4860 cubic feet.

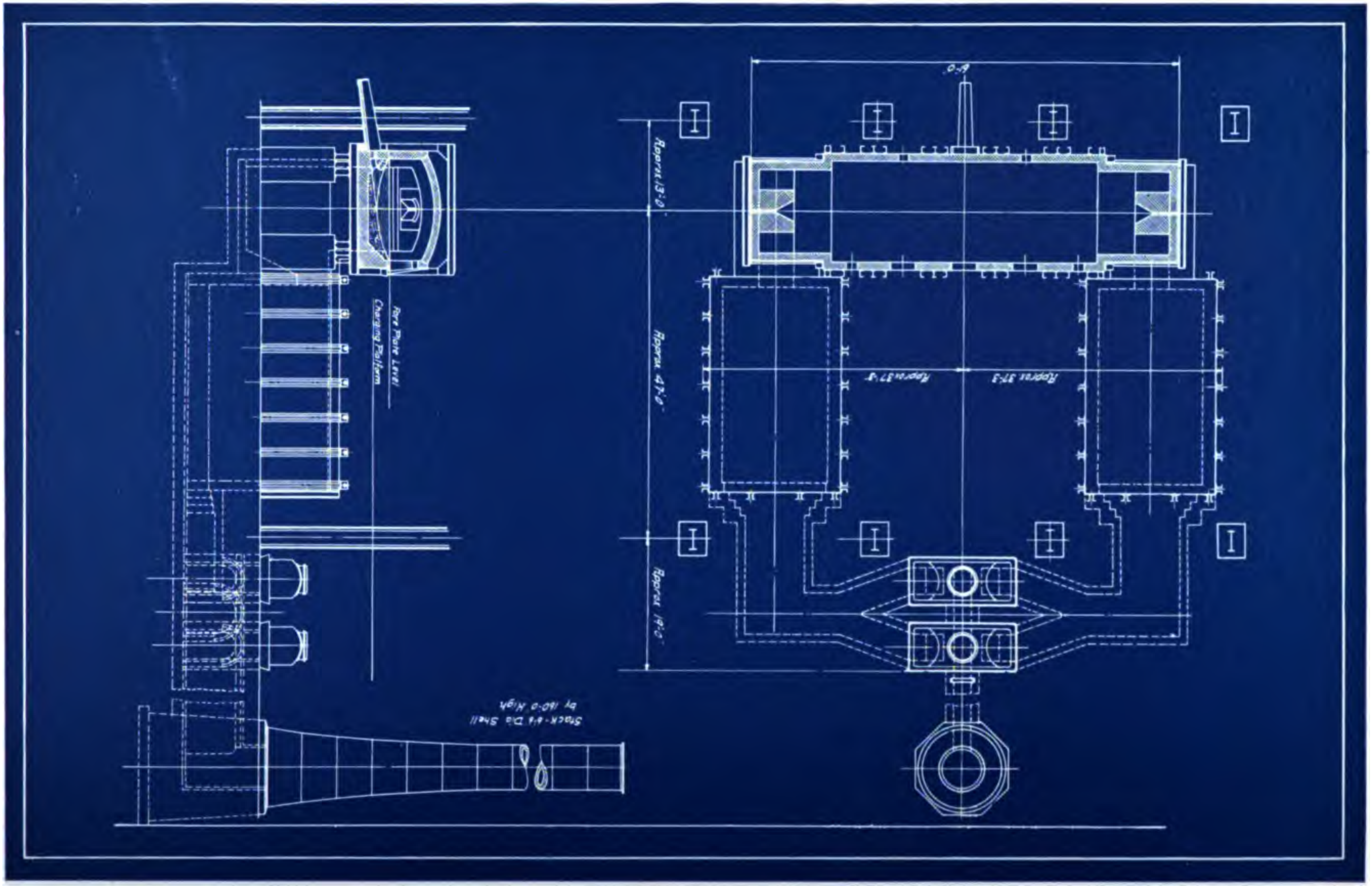


Figure 62—65-TON ACID STATIONARY WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Hearth 14 feet 6 inches by 38 feet by 1 foot deep. Area 552 square feet. Area per ton 8.2 square feet. Ratio length to width 2.62. Two 42-inch valves. Stack 5 feet 9 inches net diameter by 160 feet high.

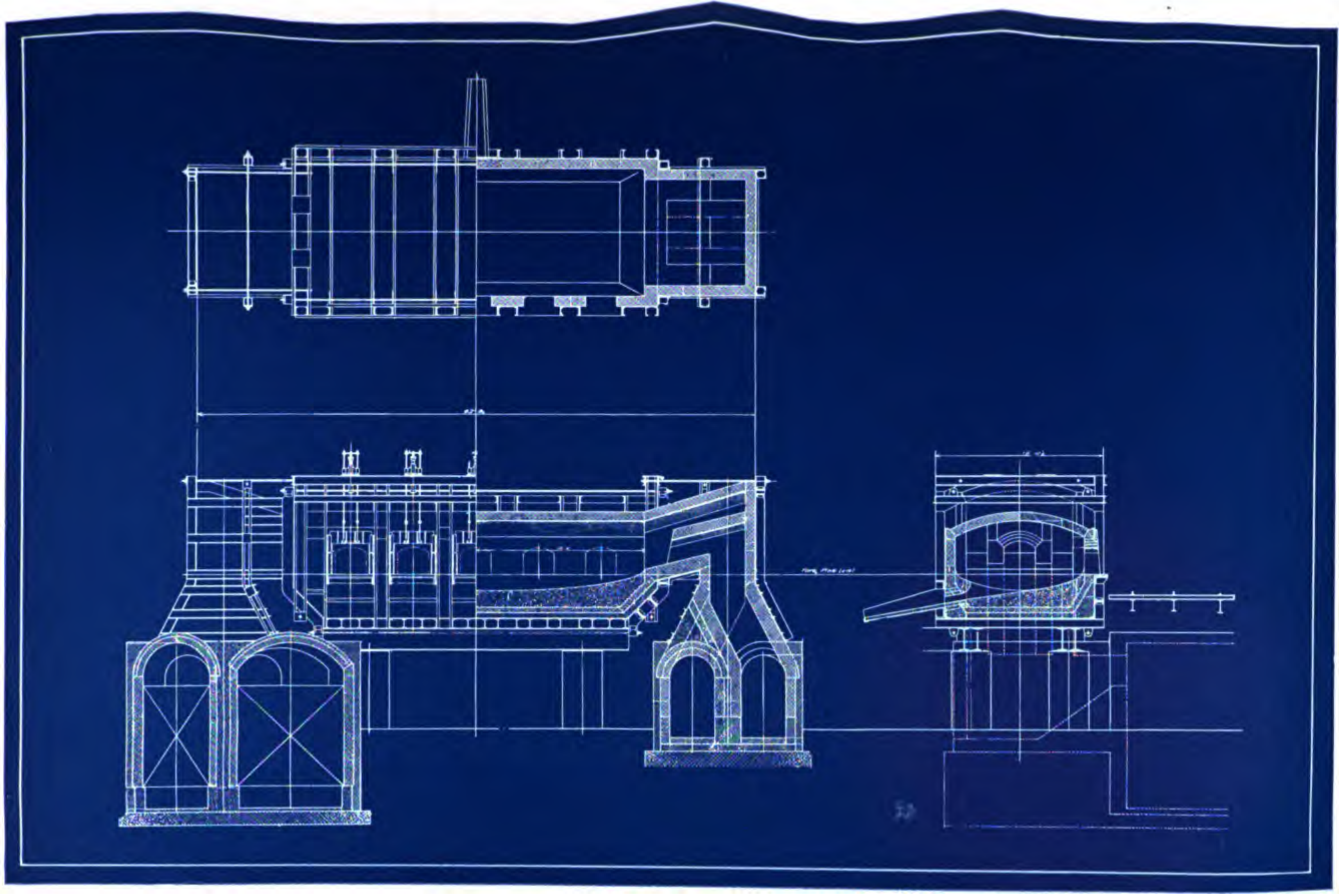


Figure 63—75-TON BASIC STATIONARY WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Doors hydraulically operated. Hearth 14 feet 6 inches by 38 feet by 1 foot 10 inches deep. 48-inch gas valve, 54-inch air valve. Stack 6 feet net diameter by 160 feet high.

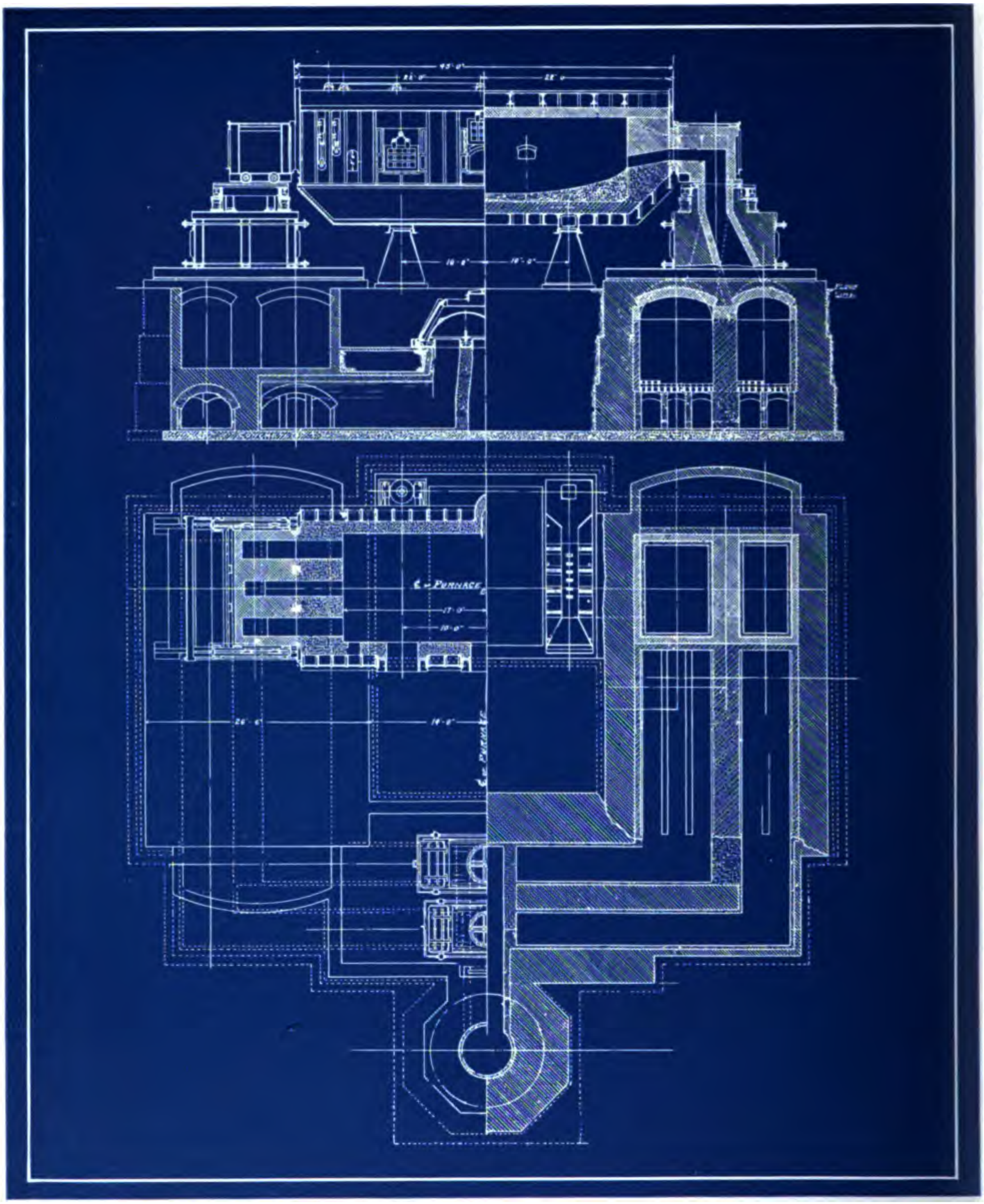
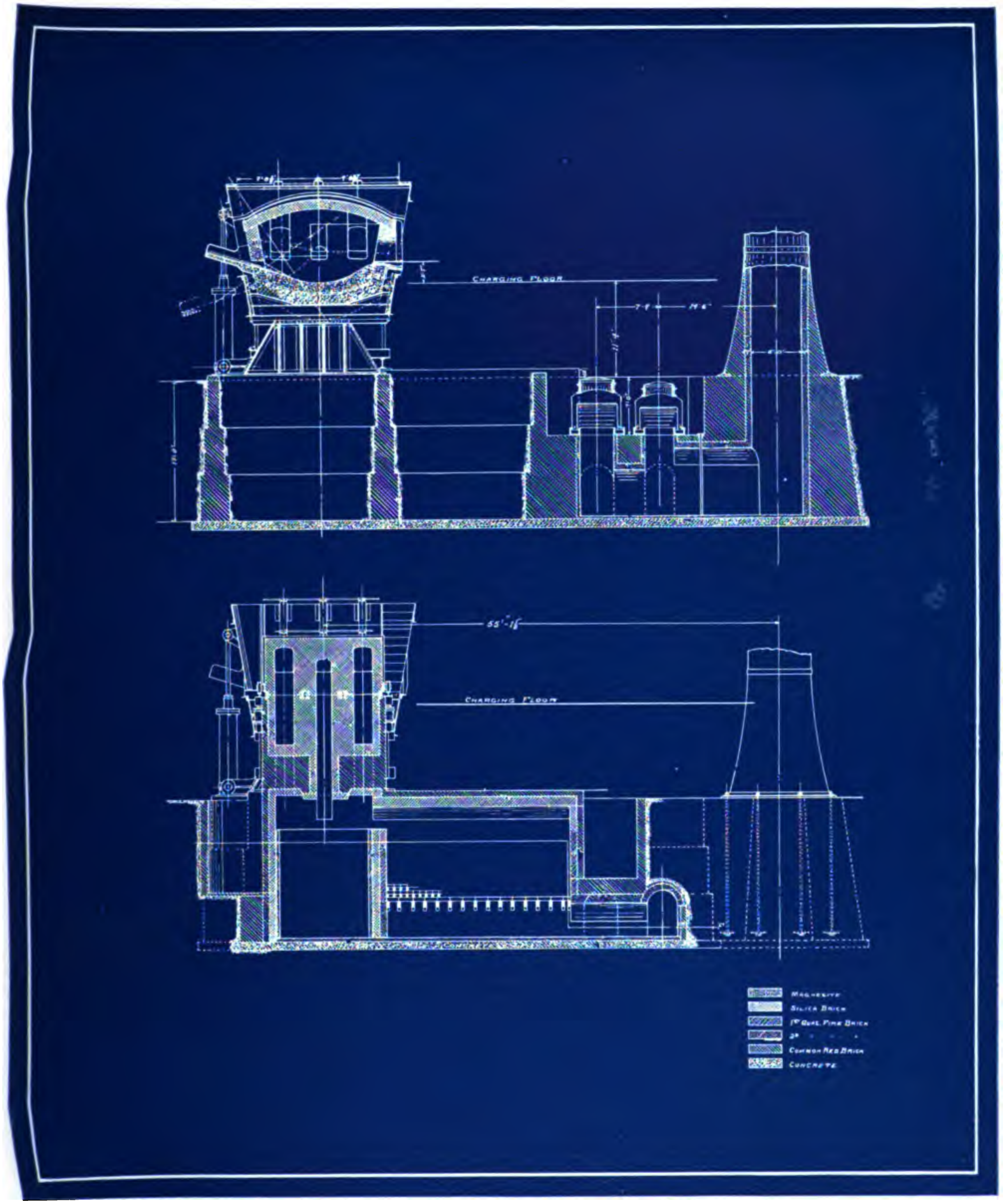


Figure 64—100-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

Built for the Frodingham Iron Steel Co., Ltd., Doncaster, England. Producer gas fuel. Tilting and door lifting by hydraulic power. The hearth is 13 feet by 34 feet by 2 feet 6



inches deep. The area is 442 square feet. The area per ton is 4.42 square feet. The ratio of the length to the width is 2.6. 42-inch gas, 48-inch air valves. The stack is 6 feet net diameter. The regenerators 8 feet 3 inches high, 22 feet long, 6 feet 3 inches width gas and 8 feet 9 inches width air. Volume 2723 cubic feet. 27.2 volume per ton.

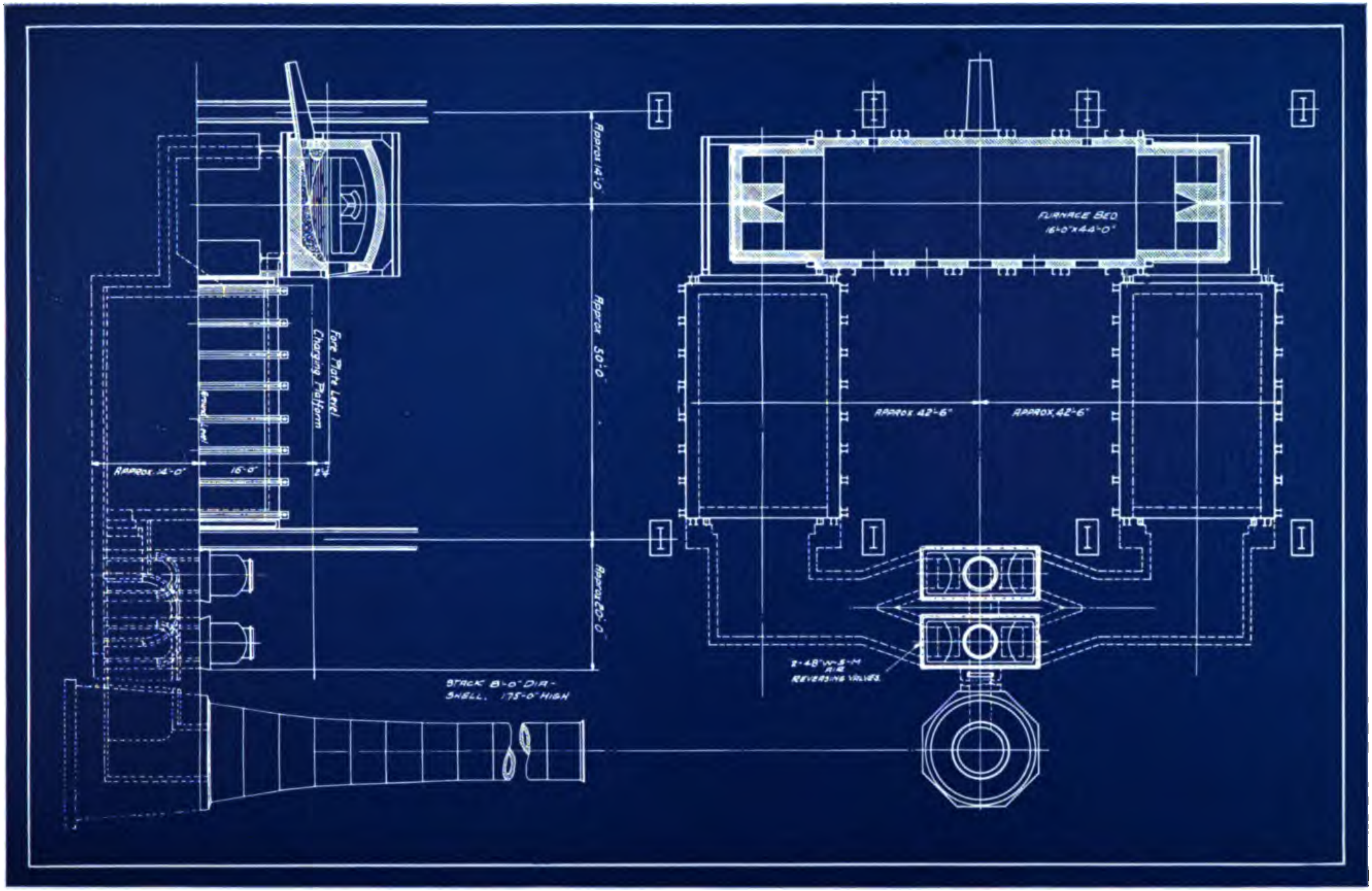


Figure 65—100-TON BASIC STATIONARY WELLMAN OPEN HEARTH FURNACE

Oil fuel. Doors hydraulic operation. Hearth 16 feet by 44 feet by 2 feet 6 inches deep. Two 48-inch air valves. Stack 7 feet 3 inches net diameter, 175 feet high. Regenerators 13 feet high, 30 feet long, 18 feet wide.

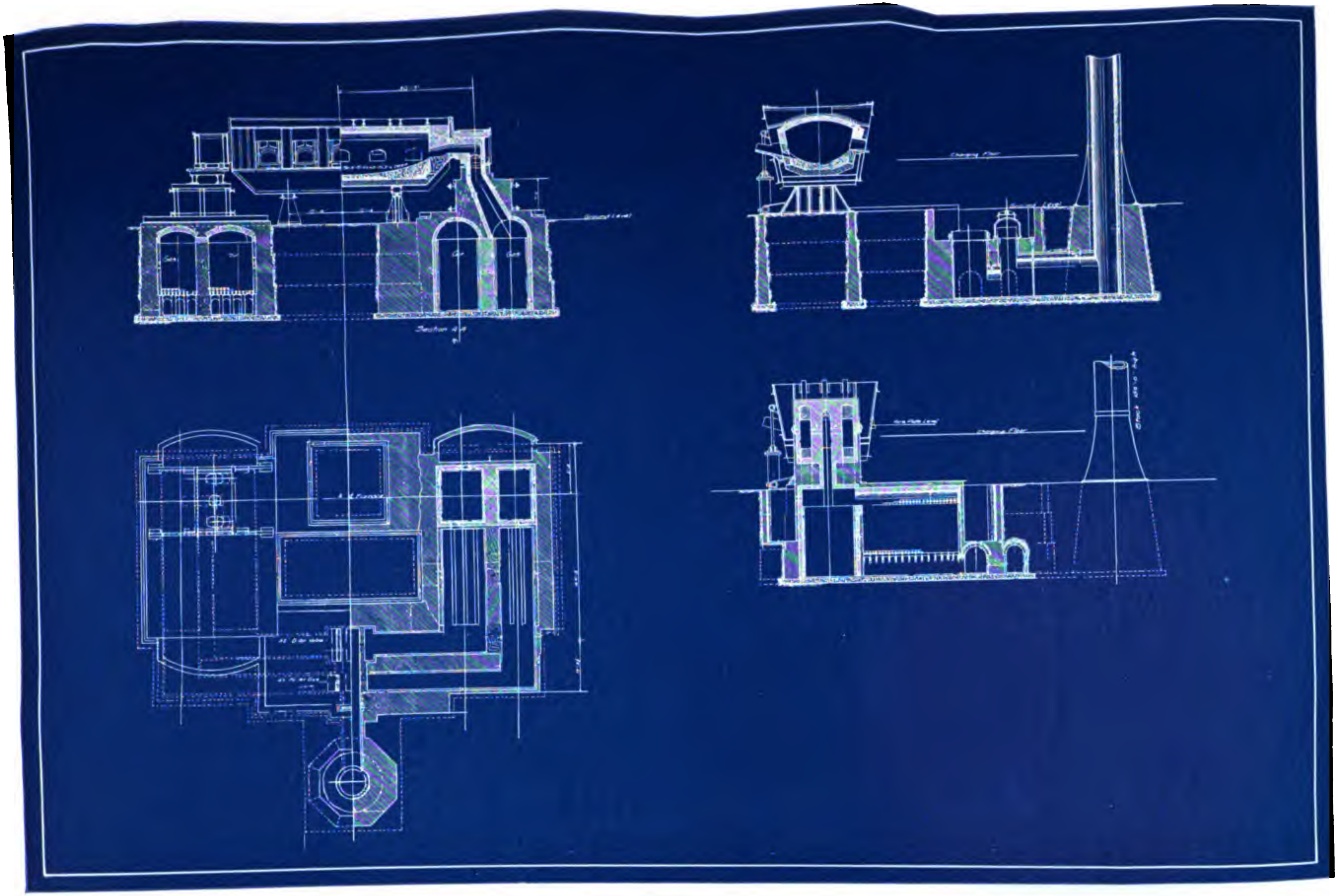


Figure 66—160-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

Built for Guest Keen & Co., Ltd., Wales. Producer gas fuel. Hydraulic operation. Hearth 15 feet by 40 feet by 1 foot 9 inches deep. Area 600 square feet. 42-inch gas, 52-inch air valves. Stack 6 feet net diameter.

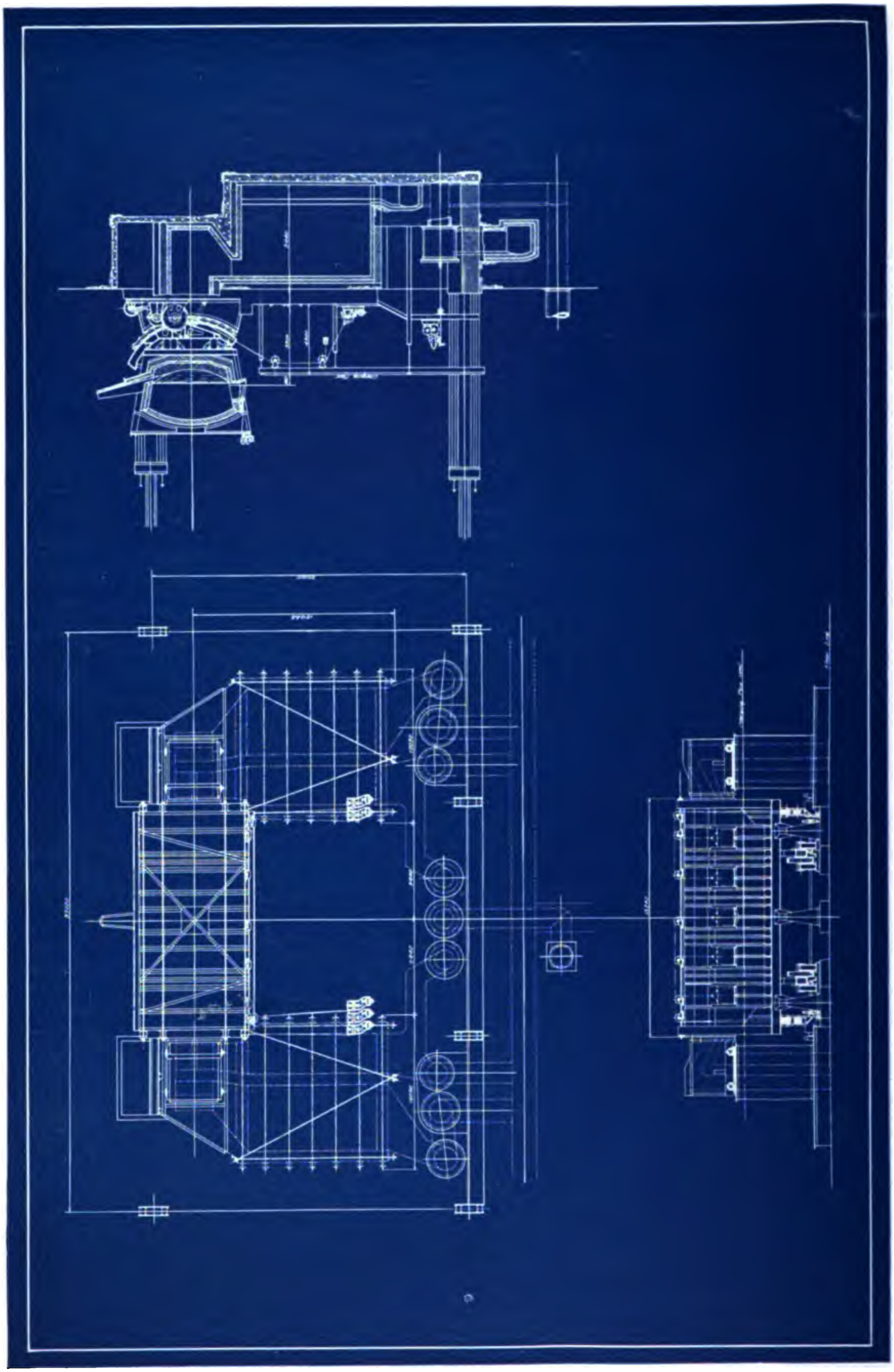


Figure 67—200-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

For Imperial Japanese Steel Works. Producer gas fuel. Electric tilting and door lifting. Hearth 16 feet by 40 feet by 3 feet deep. Regenerators 12 feet 3 inches high, 27 feet long, 8 feet 3 inches wide gas, 13 feet 8 inches wide air.

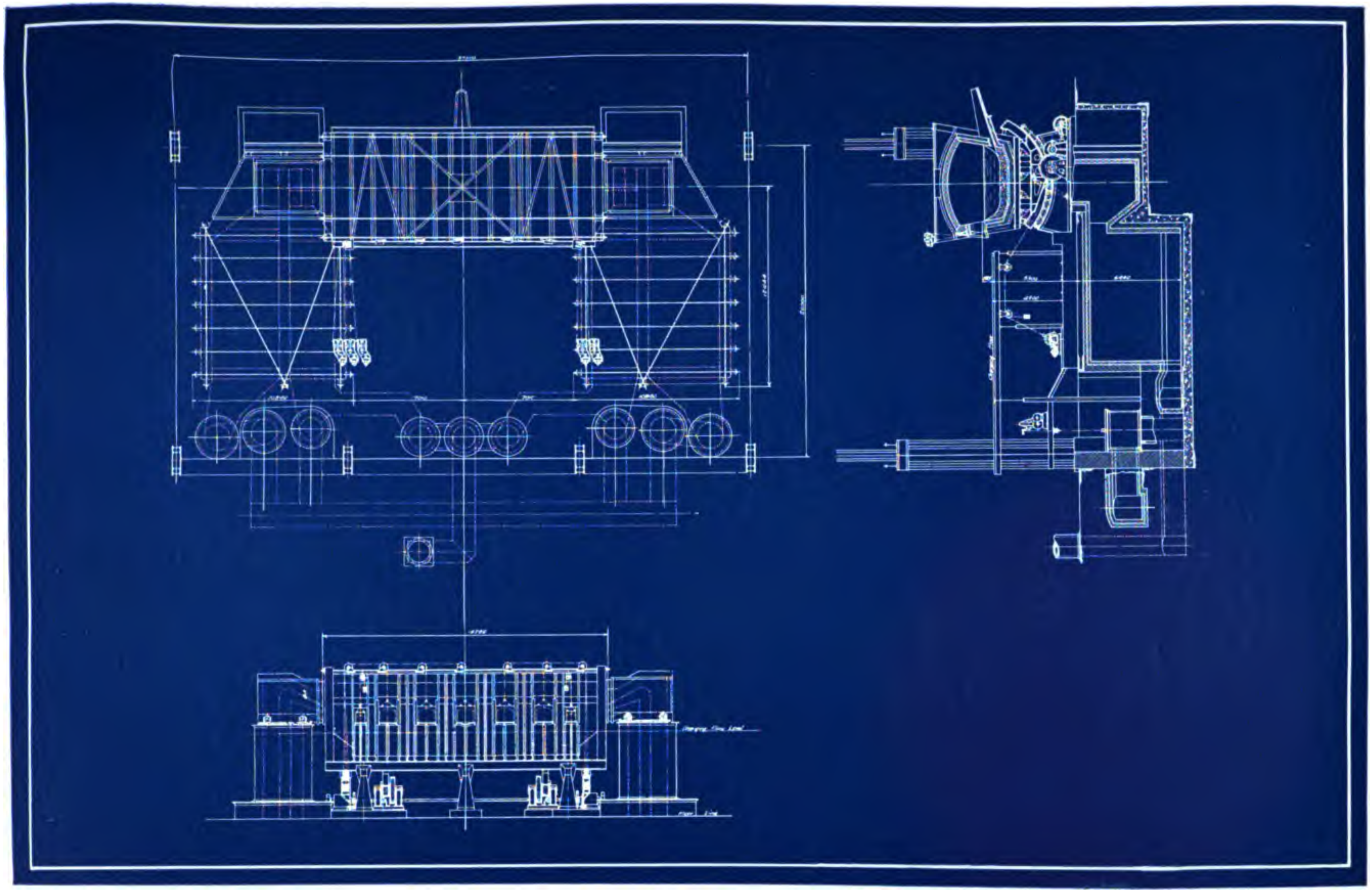


Figure 68—300-TON BASIC TILTING WELLMAN OPEN HEARTH FURNACE

Producer gas fuel. Electric tilting and door lifting. Hearth 16 feet by 50 inches by 3 feet deep. 56-inch gas, 64-inch air valves. Regenerators 12 feet 6 inches high, 27 feet long, 9 feet 6 inches gas, and 14 feet air.

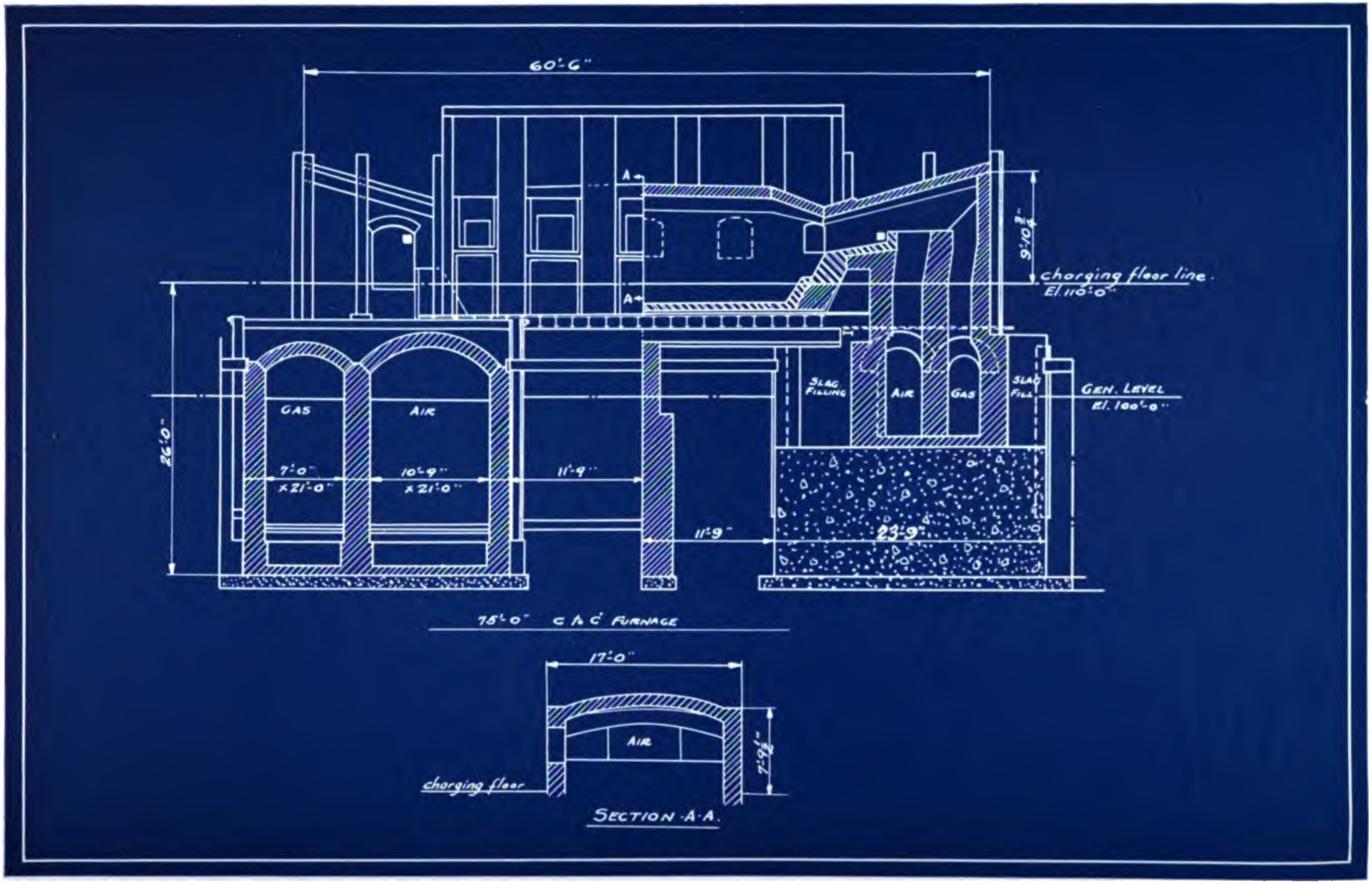


Figure 69—50-TON OPEN HEARTH FURNACE

Clairton Steel Works. 1902. Natural gas fuel, gas not regenerated. Hearth 14 feet by 31 feet. Ratio of length to width 2.22. Regenerators 21 feet long. Gas 7 feet wide, air 10 feet 9 inches wide.

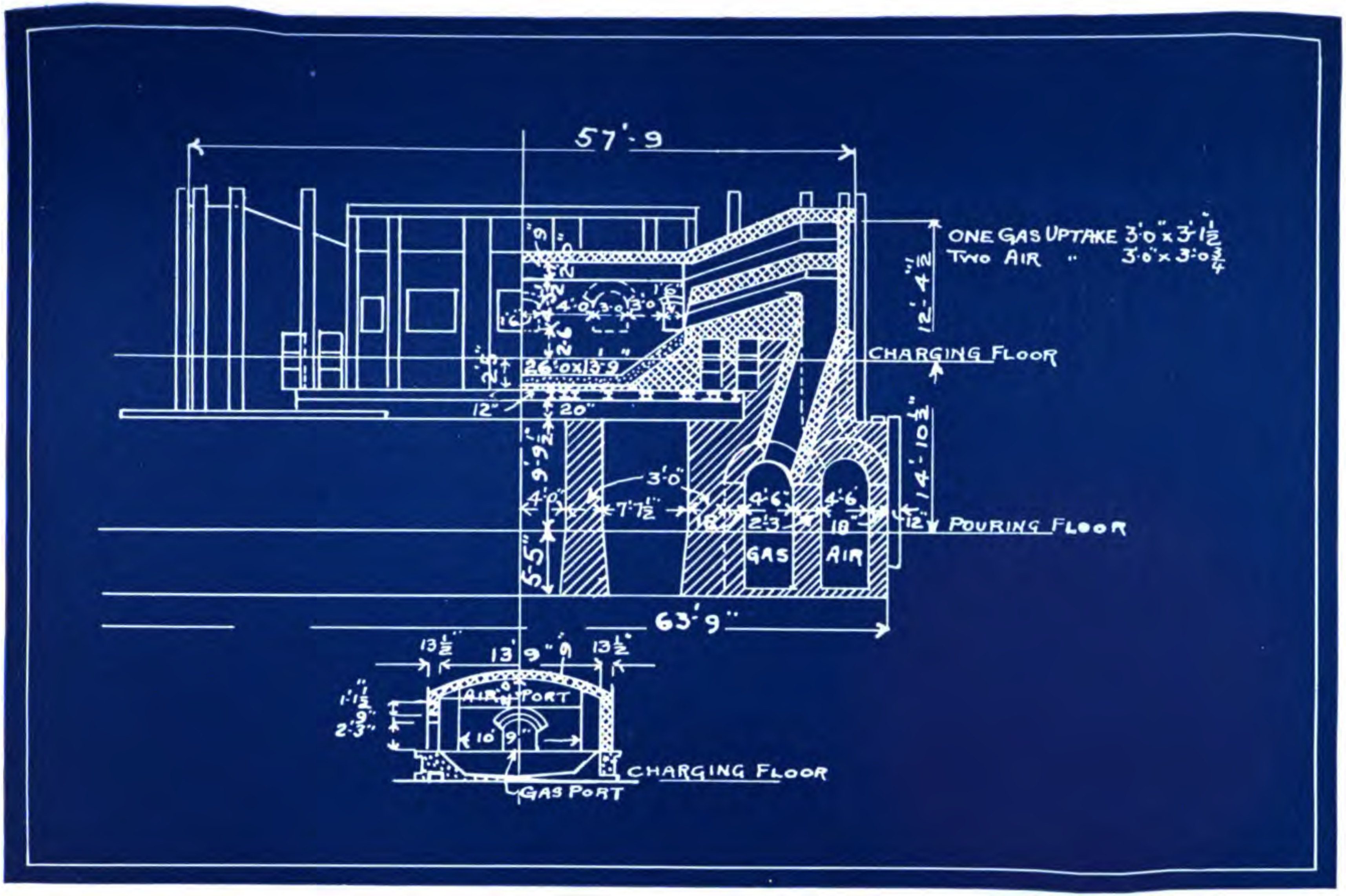


Figure 70—50-TON OPEN HEARTH FURNACE

Built for Worth Bros., Coatsville, Pa., in 1906. Gas is used for fuel. The hearth is 13 feet 9 inches by 28 feet. The ratio of the length to the width is 2.04.

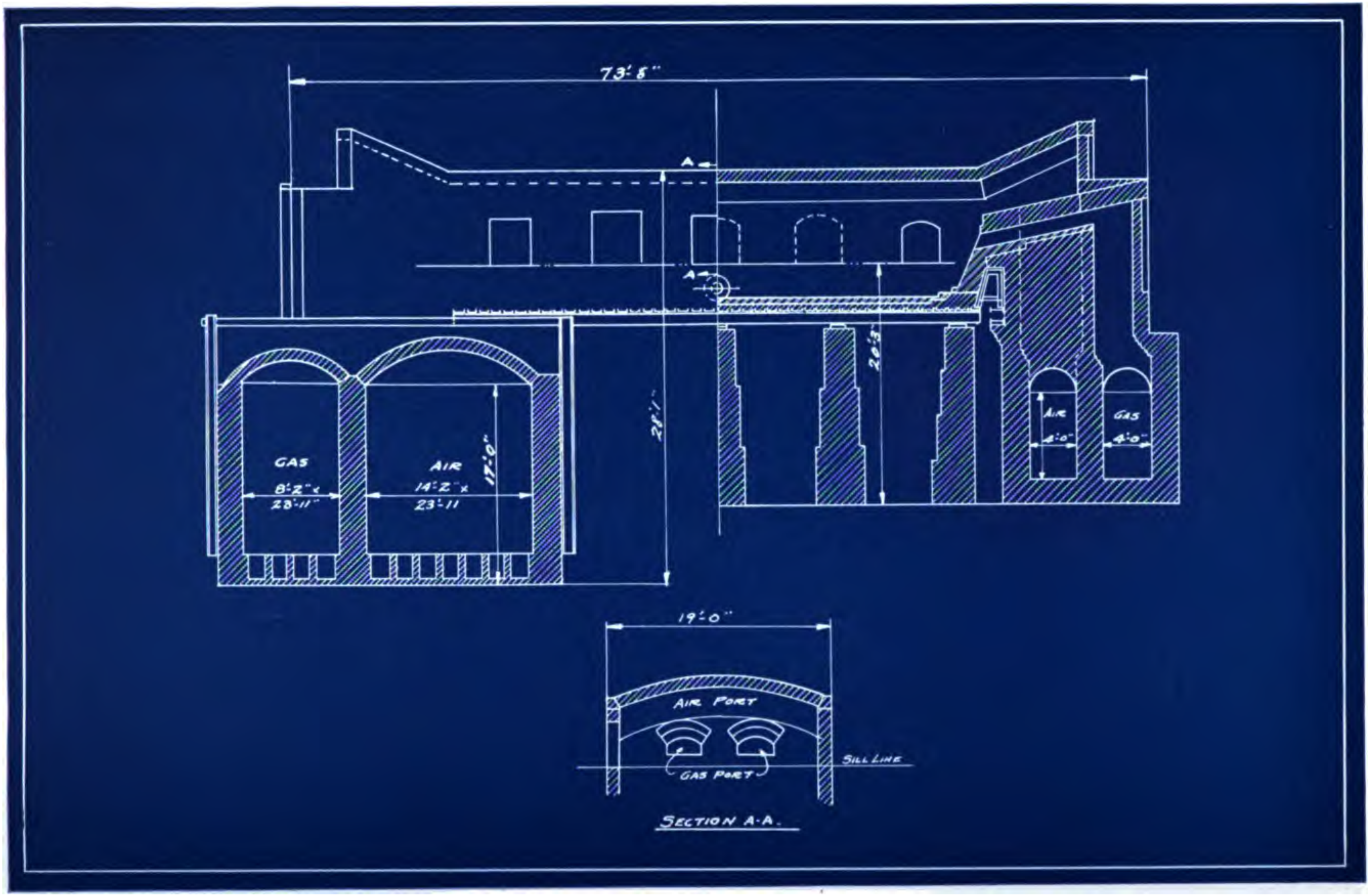


Figure 71—60-TON OPEN HEARTH FURNACE

Lackawanna Steel Co. 1906. Gas fuel. Hearth 16 feet by 43 feet. Ratio of length to depth 2.56. Regenerators 23 feet 11 inches long. Gas 8 feet 2 inches wide, air 14 feet 2 inches wide.

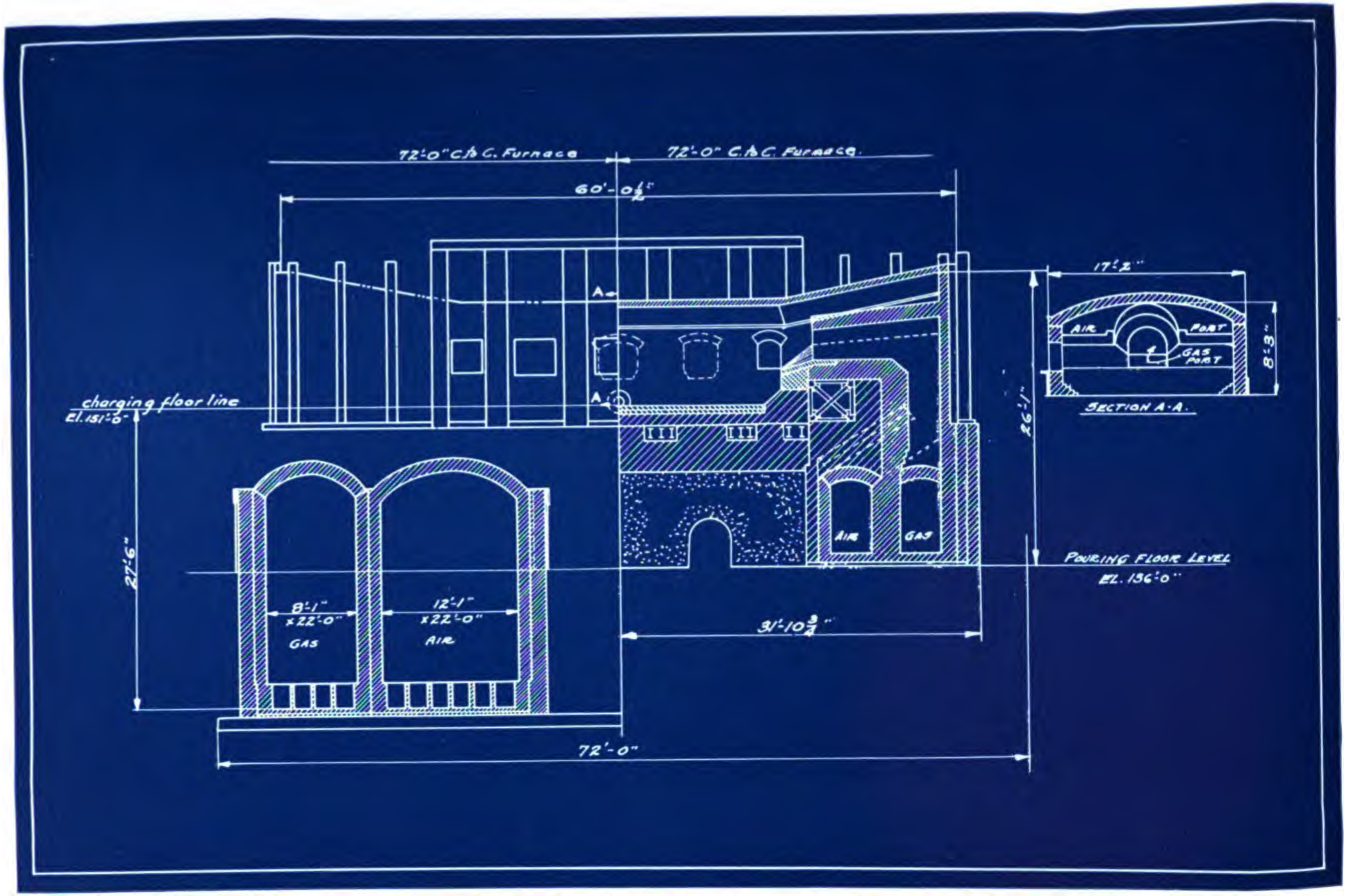


Figure 72—60-TON OPEN HEARTH FURNACE

Installed at the Ohio Steel Works. Gas fuel is used. Hearth 14 feet 11 inches by 29 feet 9 inches. Ratio length to width 2.0. Regenerator 22 feet long. Gas 8 feet 1 inch wide. Air 12 feet 1 inch wide.

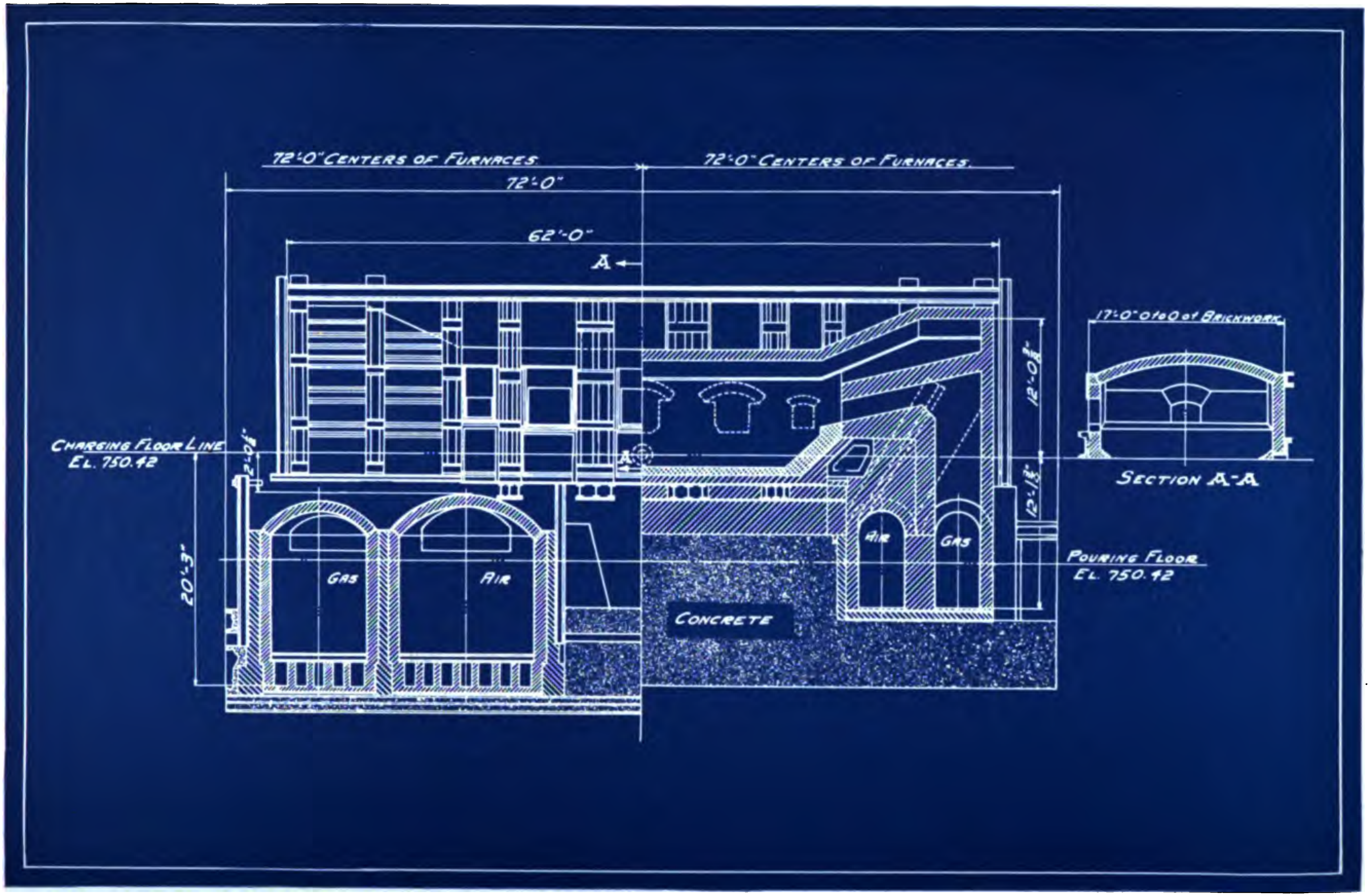


Figure 73—60-TON OPEN HEARTH FURNACE

Installed at the Duquesne Steel Works, Duquesne, Pa. Gas fuel. Hearth 14 feet 9 inches by 32 feet. Ratio length to width 2.2. Regenerators 11 feet 2 inches high, 24 feet long. Gas 8 feet 4 inches wide, air 11 feet 8 inches wide.

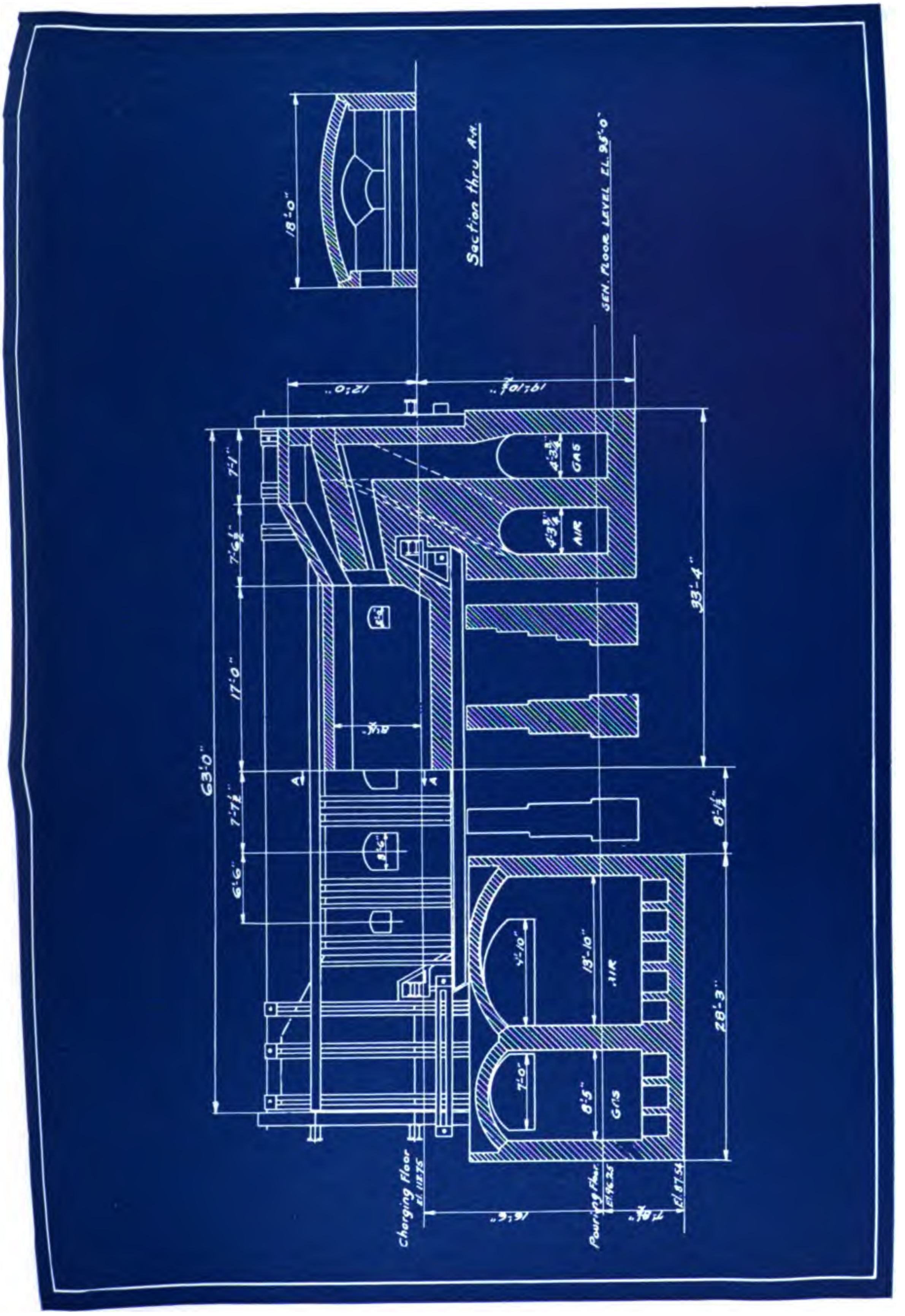


Figure 74—60-TON OPEN HEARTH FURNACE

Installed at the plant of the Republic Iron Steel Co., Youngstown, O. Gas fuel. Hearth 15 feet by 34 feet long. Regenerators 8 feet high. Gas 8 feet 5 inches wide, air 13 feet 10 inches wide.

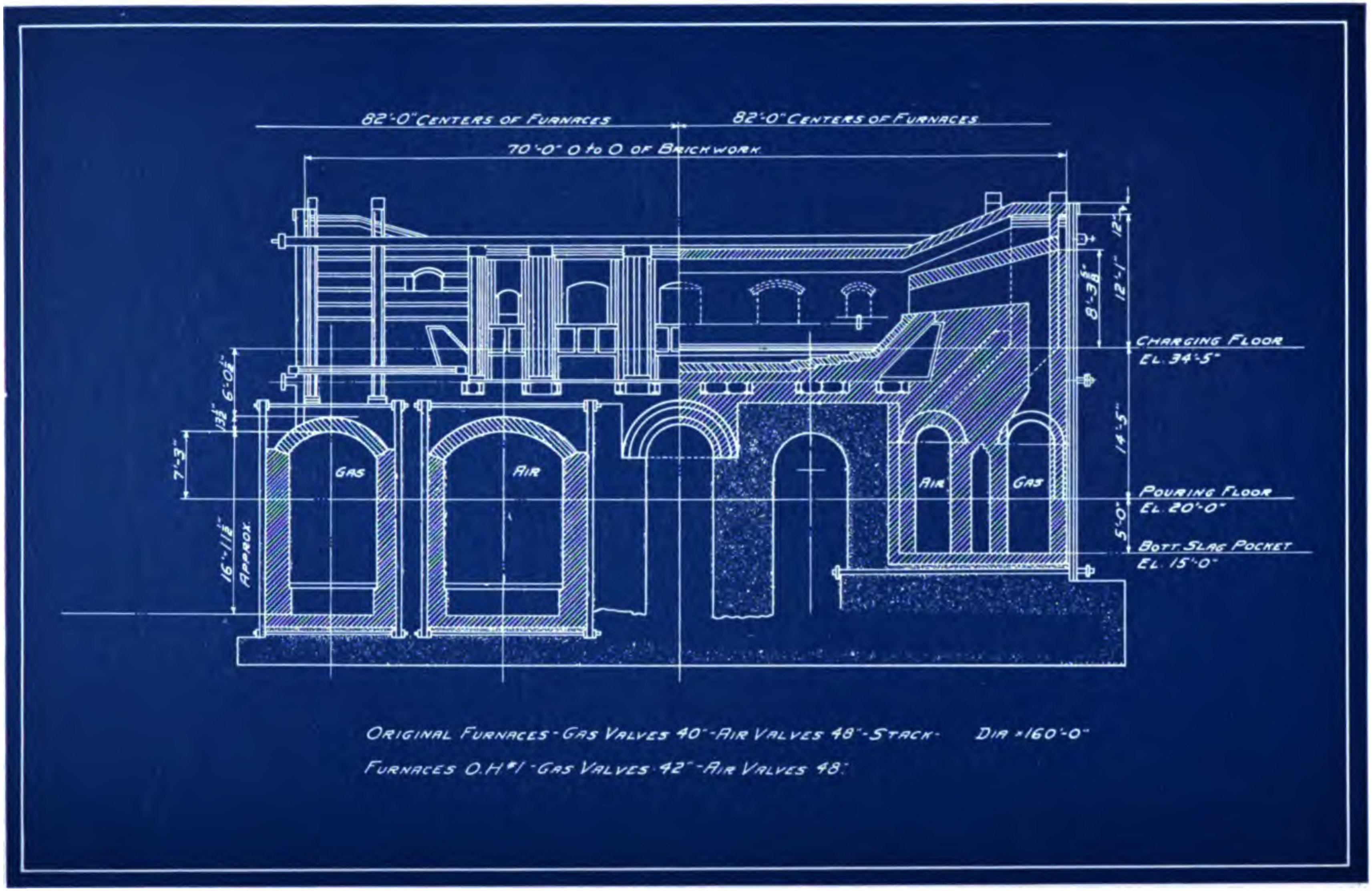

82'-0" Centers of Furnaces
82'-0" Centers of Furnaces
70'-0" O to O of Brickwork
12"
12'-1"
8'-3 3/8"
Charging Floor
El. 34'-5"
14'-5"
Pouring Floor
El. 20'-0"
5'-0"
Bott. Slag Pocket
El. 15'-0"
Gas
Air
Air
Gas
6'-0 1/2"
13 3/4"
7'-3"
16'-11 1/2"
Approx.
Original Furnaces - Gas Valves 40" - Air Valves 48" - Stack - Dia ×160'-0"
Furnaces O.H.#1 - Gas Valves 42" - Air Valves 48"

Figure 75—60-TON OPEN HEARTH FURNACE

Indiana Steel Company, Gary, Indiana. Gas fuel. Hearth 15 feet 3 inches by 40 feet. Ratio 2.62. Stack 160 feet high. Regenerator 30 feet 10 inches long. Gas 7 feet 11 inches wide, air 10 feet 10 inches wide.

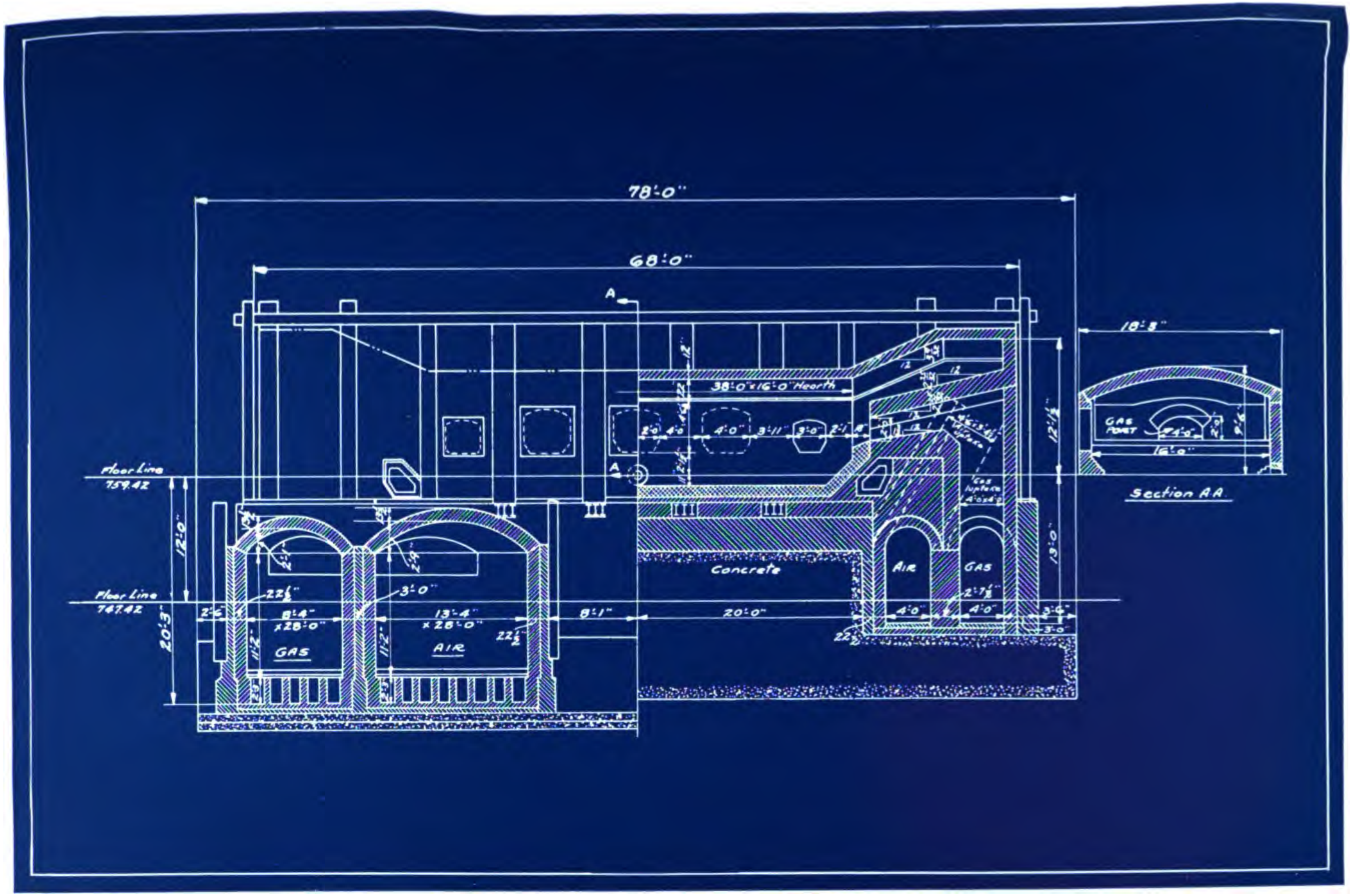


Figure 76—75-TON OPEN HEARTH FURNACE

Installed at the Duquesne Steel Works, Duquesne, Pa. Gas fuel. Hearth 16 feet by 38 feet. Ratio of length to width 2.38. Regenerator 28 feet long. Gas 8 feet 4 inches wide. Air 13 feet 4 inches wide.

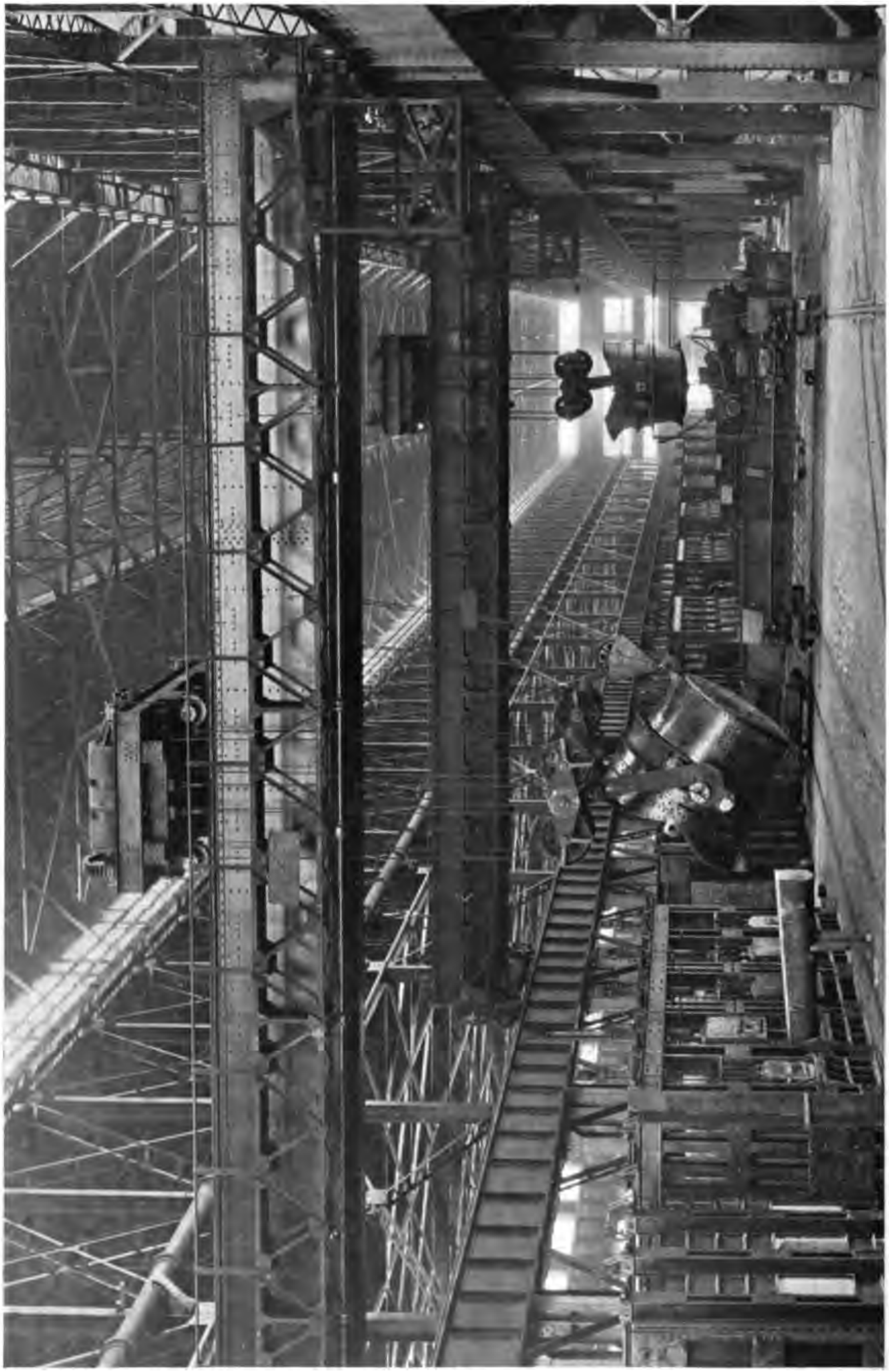


Figure 77—CHARGING SIDE OF AN OPEN HEARTH STEEL MILL

Showing the charging side of a battery of furnaces with low type charging machines and overhead cranes. In the foreground is a hot metal ladle and runner in position for charging a furnace.

CHAPTER XIV

Open Hearth Plant Equipment

An open hearth foundry may contain a single furnace. If continuity of production is desired two furnaces must be built. With three heats per day the furnace will have to be relined in about 90 days, and will be under repair for about seven to fourteen days. It should make steel about 90% of the time.

A plant of four 50-ton furnaces will need equipment as follows:

1. Two stock yard cranes of 10 tons capacity—one with a lifting magnet.
2. One "floor type" Wellman charging machine.
3. One track scales for weighing charging box cars.
4. One locomotive for stock transportation.
5. Thirty-five charging box cars.
6. One hundred and seventy-five charging boxes.
7. Five general use standard gauge cars.
8. Slag pot cars or equivalent in flat bottom slag pots.
9. Cinder yard crane.
10. A stock yard well designed for handling stock and refractories.
11. Hot metal mixer.
12. Hot metal scales.
13. One electric overhead hot metal traveling crane of 75 tons capacity.
14. Four spout cranes.
15. Two hot metal ladles.
16. Two hot metal pouring spouts—portable to fit charging machine.
17. Wellman mechanical heavy duty feed gas producers with coal bins, and ash conveyors.
18. Four open hearth furnaces, acid or basic and stationary or tilting, either by hydraulic or electric power.
19. Six steel ladles.
20. One 100-ton electric overhead traveling ladle crane.
21. Casting platform for ingots or equivalent mould floor for foundry castings.
22. Repair stands for repairing the lining and heating ladles and stoppers.
23. Ingot moulds or equivalent foundry equipment of flasks, etc.
24. "Casting on cars" equipment including car pusher, locomotives, cars, mould bottoms or stools and stripping machine and house, with operating power.
25. One set of blowers for cooling furnace for quick repairs.
26. Blacksmith shop equipment for quick repairs.
27. Full supply of refractories, such as brick, magnesite, silica cement, silica sand, fire clay, dolomite, etc., for quick repairs.
28. Pokers, sampling bars and a complete general equipment of hand tools for charging floor and for casting floors.
29. Four cast iron boxes for cooling tools, etc.
30. Charging floor—chemical laboratory.

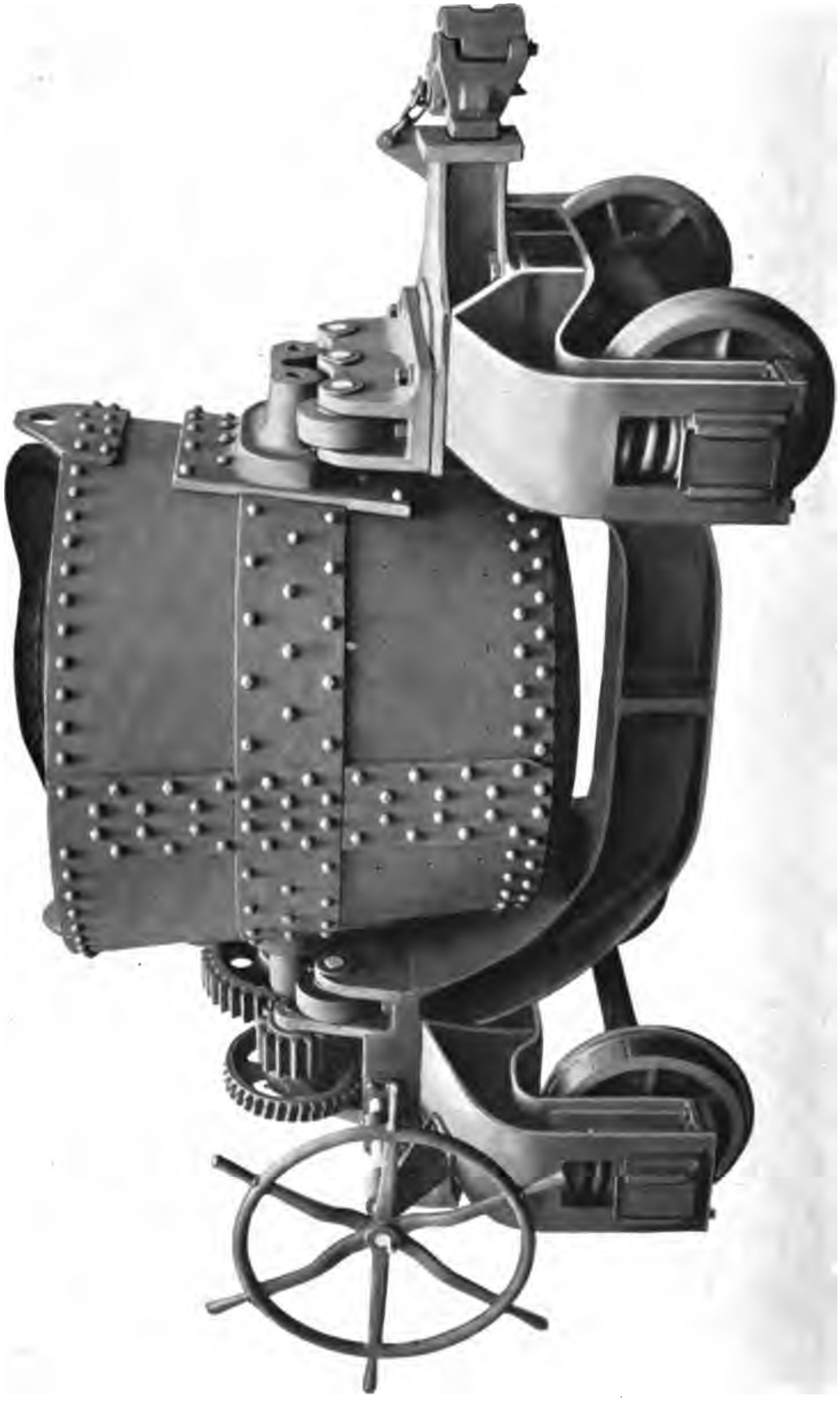


Figure 78—A 10-TON WELLMAN STEEL FOUNDRY CASTING LADLE

31. Refractory plant including
    - Calcining cupola and blower.
    - Calcining cupola charging crane.
    - 9′-0″ dry pan.
    - 9′-0″ wet pan—can be used also for sand and loam stone crusher and screen.
    - Elevator for delivering burnt dolomite to the storage bin.

If ingots are to be cast, at least fifty ingot cars should be provided, and moulds accordingly, bearing in mind that moulds last 60 heats, and stools 600 to 700 heats. An ingot scales and a mould yard with car grease pit should be provided.

Hot metal ladles for the open hearth should be provided with spouts on both sides, with a pouring lip which will allow a deep flow of metal. The trunnions should have safety notches for crane hooks. The center of gravity should be low and always below its metal center for different pouring positions to prevent overturning in case the ladle is dropped by the crane.

Practice leans toward ladles of large size running up to 40 and even 60 tons for pig metal and up to 100 tons for steel.

A portable hot metal spout is used in charging hot metal; one end resting on the furnace fore plate and reaching into the furnace. The other end is supported by legs fitted to its under side. It is lined with fire brick and the sides are made high to prevent splashing.

Waste Heat Boilers

Since the temperature of the flue gases in an open hearth furnace are at a temperature of approximately 1200° F., and the volume of these gases is very great, attempts to conserve this waste heat have been made with encouraging results. A standard 50-ton open hearth furnace will furnish enough gas to operate a 175 bhp. boiler but requires a specially designed boiler to do so as the heating surface has to be much greater than in a coal fired boiler. A boiler with 2000 sq. ft. of heating surface has an efficiency of 70% when operated on the flue gases from an open hearth furnace. The value of this horsepower (175) amounts to \$50 per bhp. year or \$7,750.00 per furnace year. The operating expense connected with such a boiler amounts to \$20 per bhp. per year so that there is a net return of \$4,250. per furnace year when equipped with a waste heat boiler.

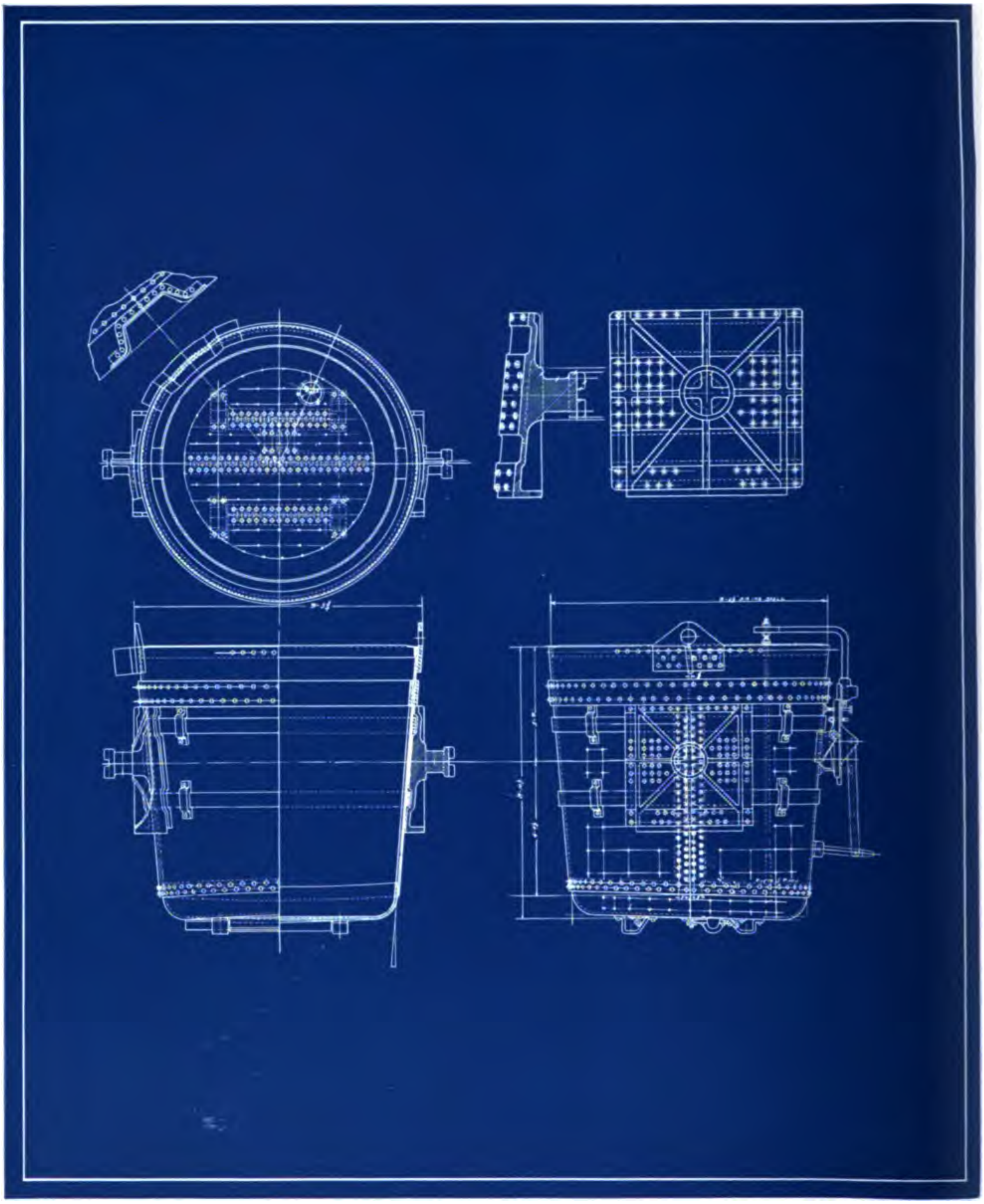


Figure 79—A 50-TON WELLMAN STEEL LADLE

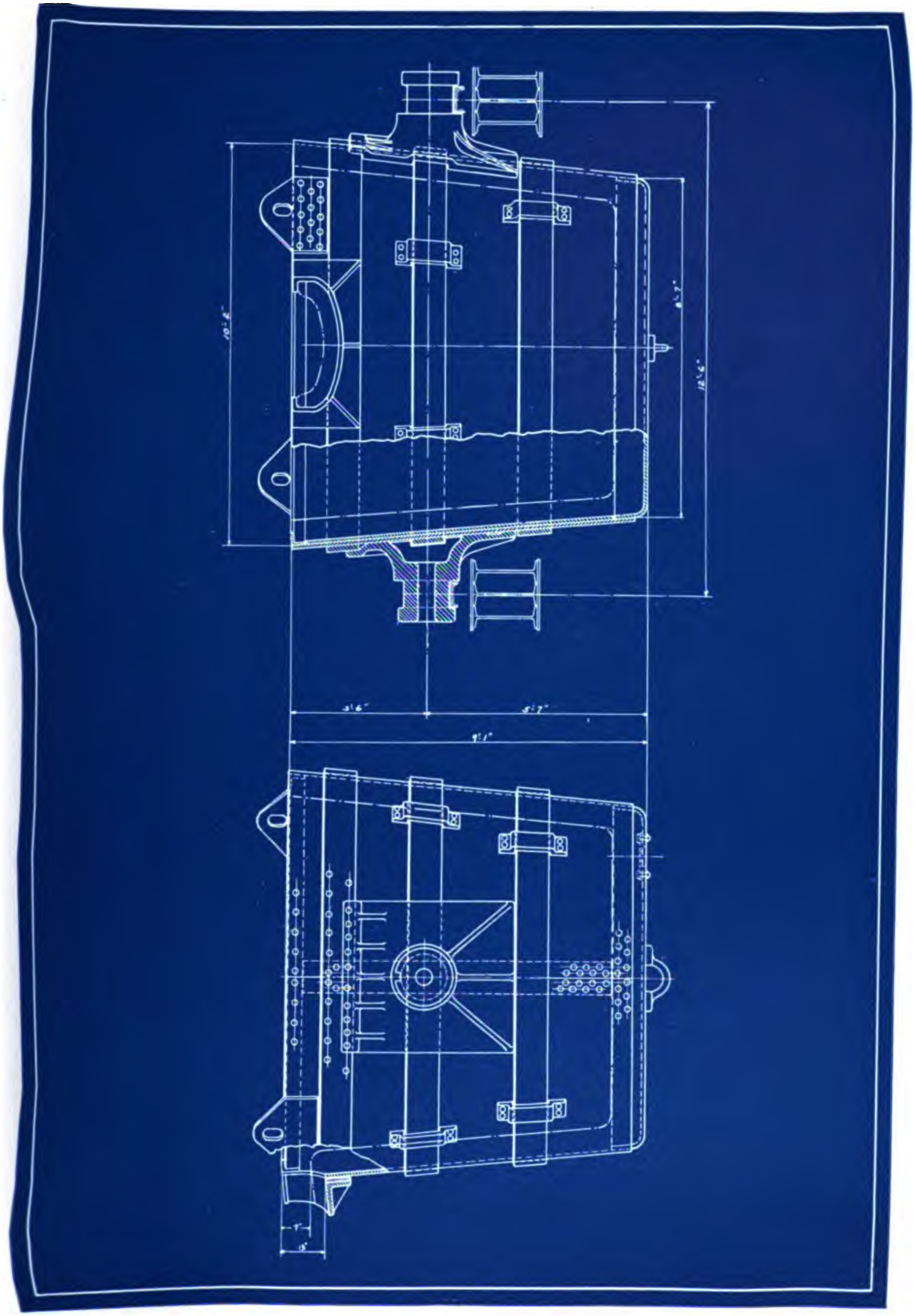


Figure 80—A 75-TON WELLMAN STEEL LADLE

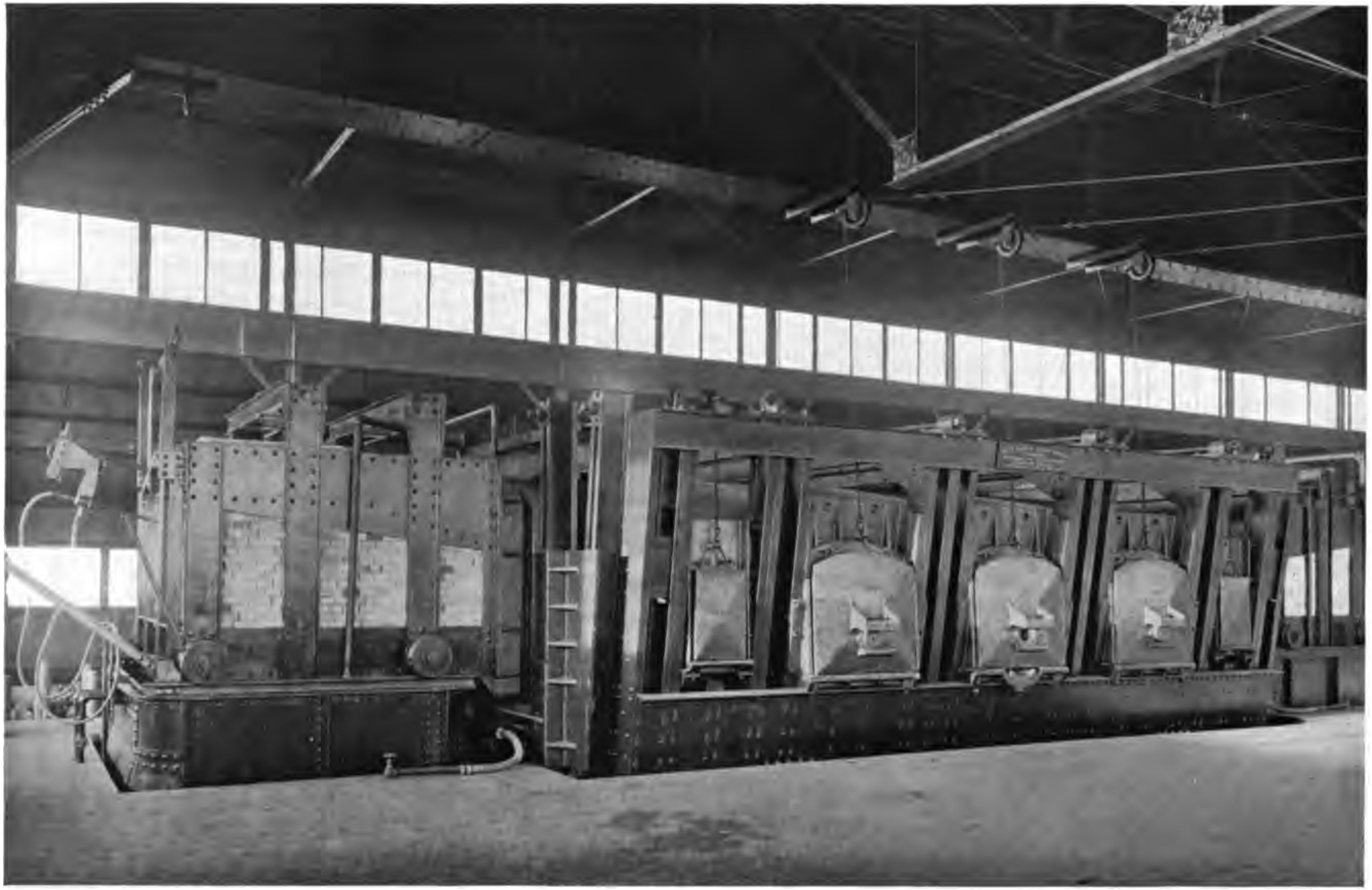


Figure 81—20-TON ACID TILTING WELLMAN OPEN HEARTH FURNACE

Installed in the works of the Halcomb Steel Company, Syracuse, N. Y., and equipped with movable parts. The first steel made in the open hearth electric furnace duplex process was made in this furnace.

CHAPTER XV

Furnace Specifications

In preparing specifications for open hearth furnaces, engineers will find the following form of value.

A __-Ton Tilting Open Hearth Steel Furnace

Proposal No. __

1. DRAWING:

Drawing No. ——, giving the general arrangement and principal dimensions of the furnace, accompanies and forms a part of this specification.

2. FURNACE HEARTH:

—′—″ width, —′—″ length; —′—″ depth

—sq. ft. bath area.

3. CAPACITY PER HEAT:

—— Tons of 2000 lbs.

—— Tons of 2240 lbs.

—— Tons metric.

The furnace as designed and proportioned, regarding the sizes and ratios found in its several parts, operates most advantageously when producing heats of the tonnage herein specified. In emergencies, however, larger heats may be melted with a somewhat decreased efficiency.

4. FUEL:

The fuel to be used will be
Natural gas
Producer gas
Crude or residuum petroleum oil
Powdered coal

The furnace is designed to permit the change from one to another of these fuels, by minor alteration of the port end brickwork.

5. FURNACE:

The furnace is designed and built according to the general and detail drawings, which are based on the following conditions and particulars:

(1) TYPE OF FURNACE.

The refractories used are those required for the basic process of steel making.

The bed, walls, and roof, of the melting chamber, ports, flues, and regenerators together with checker work and stack are built of selected materials, shapes being of such dimensions as to secure a maximum of endurance and heat retention possible in the best modern open hearth furnace practice.

6. FURNACE FRAMEWORK AND BUCKSTAYS:

The furnace brickwork is contained in a heavy steel framework of plates, structural steel shapes and castings which are carried at each end on heavy steel segmental circular rockers. On these are cast large lugs or teeth to mesh with a correspondingly toothed rack on each side of which are wide flat treads. Two cast steel pedestals support the entire weight of the furnace, the whole being carried on concrete foundation piers of ample proportions.

On the spout or pouring side extending along the length of the furnace is a platform giving easy access to the tapping hole.

Buckstays of structural shapes extending from the furnace floor beams to a point above the roof arch are buckstays of structural shapes. These are tied across the furnace top by beams riveted to them forming a complete and securely bound structure.

At the rear of the furnace is placed a structural and plate steel, fire brick lined spout of ample proportions through which the hot metal will run into the ladle.

7. FURNACE DOORS:

The furnace doors and their frames are of cast steel, air cooled and brick lined. The doors may be opened or closed irrespective of the position of the furnace. Operation is by hand, hydraulic or electric power as required.

8. FURNACE MANIPULATION:

Doors, burners, valves and damper may be operated by one man from a position at the back of the charging floor, where everything, including the pressure gauges, will be within his view, and under immediate control.

9. METHOD OF OPERATION:

The furnace may be tilted to such positions as to allow the pouring of any portion, or all, of the molten metal at the will of the operator. The operating mechanism will be actuated by $\left\{\begin{array}{l}\text{hydraulic}\\ \text{electric}\end{array}\right\}$ power.

The hydraulic operating cylinders are designed for a working pressure of 500 pounds per square inch. They are of heavy construction and ample capacity mounted on trunnions firmly anchored to the foundations.

The electrical operating mechanism consists of a — H. P. motor actuating a train of gearing composed of steel spur gears with a worm and wheel driving a pair of heavy shrouded steel rack gears with a corresponding steel gear on the furnace framework. This mechanism is adequately protected by covers from heat, splashings, and dirt, which also act as safeguards for the operators. This tilting device is designed to be self-locking, to control and hold the furnace in any position desired by the steel melter.

10. PORT ENDS:

The steel framework of the ports forms an integral part of the furnace frame, rolling with the furnace as it tilts and eliminates joints and gas leakage, common to tilting furnaces with detached port ends.

A water seal is located at the junction of the port ends and uptakes, making a gas and air tight joint. This water seal is of the latest approved design, and of heavy sections presenting a minimum exposed water surface to action of the hot gas.

The life of the regenerator checker work will be prolonged by ample slag pockets below the ports to receive and hold slag carried out of the furnace by the burnt gases.

11. REGENERATORS:

—′—″ length, —′—″ breadth
—′—″ height

Ratio of gas to air approximately 1:1½.

The volume of checker work per ton of steel capacity varies from 70 to 90 cu. ft. depending upon the fuel used, and the size of the furnace.

The ratio of the length to the depth of the checker-chambers is such as to give the maximum efficiency and most advantageous operation of the furnace under all conditions of steel making.

The regenerator binding consists of heavy steel framing, securely bound together and firmly anchored to the foundation of the regenerator chambers.

12. REVERSING VALVES AND DAMPER:

Between the regenerators and stack and connected to both by fire brick flues, are located the reversing valves of the improved W-S-M type, water sealed and operated simultaneously through wire ropes running over sheaves to stands.

A suitable damper of a highly refractory and durable material is provided for the flue between the valves and the stack.

The valves and damper are operated from the charging floor.

In addition to the customary method of operation, this furnace may also be used in the duplex process of making soft commercial steel in the open hearth from scrap and pig iron, the refining being carried on in an electric furnace. In this case a charge for the electric furnace will be tapped off in two or more hours and a corresponding amount of cold stock charged.

The Wellman tilting furnace is peculiarly adapted to the requirements of the duplex and the triplex processes.

13. STACK:

—'—" high, —'—" diameter

—'—" diameter inside of brick lining.

The stack is of steel plates —", —", —", —" from the baseplate upwards, and lined with fire brick. It is securely fastened to a heavy cast iron base anchored to the foundation and is self supporting.

14. MATERIAL AND WORK INCLUDED IN THIS PROPOSAL:

It is proposed to furnish and build complete in place ready for drying and making bottom as follows:

1. Metal framework, supports, bindings, baseplates, and shell of furnace, operating mechanism, spout, regenerators, valves, damper and stack.
2. Electric motors with brakes and controller for tilting furnace and motor with controller for operating doors.
3. W-S-M type of gas and air reversing valves, and damper and frame.
4. Two oil burners.
5. Oil pumping system from and including oil pump near furnace to burners.

15. CLIENT TO SUPPLY AND ERECT:

The client is to supply and connect for operation all electric wiring and apparatus other than specified in paragraph No. 9, also all water and waste piping leading to and from the furnace, also all water, electric and hydraulic power and fuel used in testing or trying out the furnace or its parts and for drying the brickwork and "burning in" the bottom.

16. DRAWINGS:

Drawings of the foundations and brickwork together with an order list of common brick and refractories will be furnished by the contractor.

17. WORKMANSHIP AND MATERIAL:

All workmanship is of the best.

Materials are of the kind and form best suited for the requirements of the construction.

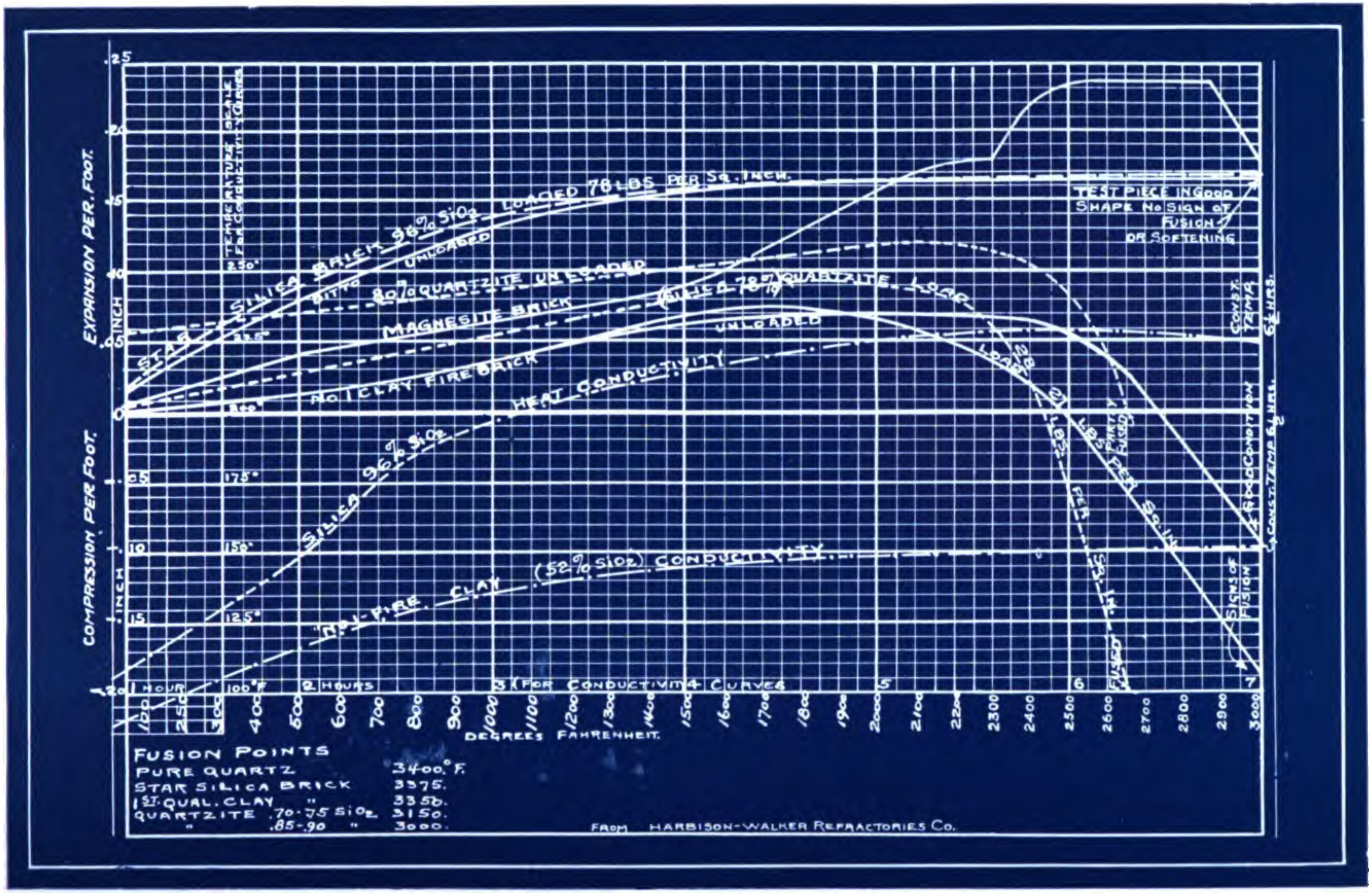


Figure 82—DIAGRAM OF EXPANSION AND CONDUCTIVITY OF REFRACTORIES

CHAPTER XVI

Refractories

The earning power of a furnace depends upon the judgment and care exercised in the selection of the correct kind and quality of brick for each of its parts, and equally upon the care with which the masons do their work. An eighty-ton furnace will contain about 1,000,000 brick, while a forty-ton furnace will require about 700,000. The expense of the masonry is a serious item, as that is the part of a furnace which most often requires renewal. The total output of the furnace is dependent on its durability. Thus a shut-down of say two weeks for relining and repairing an eighty-ton furnace means a loss of output of about 2500 tons of steel. In the meantime the overhead expense goes on.

Considerations on which the selection of refractories depend are:

1. The working temperatures of the various parts of the furnace.
2. The nature of the materials with which it will come in contact.
3. The slag whose chemical action it must resist.
4. The scouring action of the impinging flame and gases.
5. The hot and cold static loads and arch thrusts imposed.
6. The abrasion to which it will be subjected from metal or slag.

The functions of fire brick are to form a chamber and passages to contain and conserve the heat of the fuel and hold the metal and slag of the bath. In an acid open hearth silica brick are used for the bed, sides, roof and ports of the furnace. The hearth is made of silica sand sintered into an impervious mass. The life of a well made acid furnace will approximate one thousand heats.

In a basic furnace magnesite is used in place of silica for the bed and sides at the slag line, although chrome brick is occasionally used for the sides. Under a great heat chrome brick yields to the compression due to the weight of the walls and roof above it.

Much experimenting has been done to find a cheap suitable basic material for a basic furnace which is reasonably abundant in this country. General practice favors a sintered bed of magnesite glazed over with dolomite.

For basic furnaces much caution should be exercised in departing from the standard practice of using the best magnesite. Experience during the war and the recent steel strike has developed the fact that in a number of instances in furnaces of average large size the dolomite bottoms had slacked to such an extent as to necessitate their replacement by magnesite.

The best practice calls for at least one or two courses of magnesite brick laid on the steel bottom of the furnace. On top of this the grain magnesite is built up by sintering to the required thickness and shape of bed in which the charge is melted and steel refined. On account of the cessation of imports from Europe during the war the supply of the best magnesite (which comes from

Austria) was cut off. Various substitutes have been tried. One of the best of these is a magnesian compound called "syndolag." A silica sand or a magnesite which is chemically too pure or free from impurities will not "sinter" successfully. Therefore for acid furnaces an impure synthetic silica sand is used having the following analysis:

Table No. 53

SiO_2	97.25%
AL_2O_3	0.16%
CAO	.18%
MgO	.40%
Alkali	.36%
H_2O	.24%
Ignition losses	.36%

The value of refractories for furnace work is determined not alone by chemical composition, but also by their physical attributes.

In the substitutes for Austrian and Greek magnesite which are used, the body of the material is dolomite mixed with iron oxide, mill scale or ore. These oxides retard the slaking of the dolomite, but reduce the refractoriness of the dolomite. Good results have been obtained by some of these substitutes used in hearth making or patching.

An efficient substitute for magnesite brick is found in "metalkase" brick. These are a basic or neutral brick of oxide of magnesia enclosed in an open end thin cylindrical or square steel shell. The open ends are laid exposed to the flame in the furnace. The brick are laid in a pulverized magnesite mortar. Under the furnace temperature the brick shells oxidize and fuse with the magnesite forming a solid mass of the furnace lining. These brick have a long life as spalling does not occur, nor is the fused combination of magnesite and iron oxide attacked by the iron oxide vapors from the bath, as is the case with silica brick. When additions to the bath are made, especially of hot metal, the violent boiling of the metal splashes the walls with slag and metal. In the case of silica brick this causes severe erosion, but has little effect on the metalkase brick. Another place of severe and rapid wear are the silica gas port bulkheads, due to the erosion of the very hot gases carrying oxide of iron. An evidence of the durability of magnesite and metalkase is given in the working of a 250-ton furnace. The magnesite backwalls lasted on an average of 450 heats. Metalkase when used lasted 1400 heats.

The hardness of burning in general is a factor worthy of consideration, although firing to a high temperature can not, in the nature of the case, effect any fundamental change, and cannot convert a low grade material into a good one. Experience has shown that well burnt bricks stand up better than soft burnt products. Refractories cannot be fired at too high a temperature. The superiority of high fired over low fired ware from every standpoint, especially as regards change in volume when part of the furnace wall, is so striking that every effort should be made to push to the maximum possible burning temperature.

In regard to the fluxes present in a clay the state and size of grain of the iron is of importance, for it is evident that coarser grains of iron minerals will do no harm.

A clay with a high volume shrinkage subjects the structure of the products into which it enters to a severe strain, which, owing to the low tensile strength, may cause serious difficulty owing to cracking and checking. It may be necessary either to calcine the flint before incorporating it in the body, or to replace it in part by ground waste brick (grog). At cone 14 of the Seger series of temperature measuring cones the shrinkages show as follows:

Table No. 54

Pennsylvania flint (Clearfield Co.)	5 %
Maryland flint	5⅓ %
Kentucky flint	9¼ %
Ohio flint	9 %
Moxahala flint	3⅓ %

A clay with a low fire shrinkage gives a product with a minimum of internal stresses and strains, of high tensile strength and one that will stand up well under heat and load conditions.

If a fire brick is dark colored, it probably contains a considerable proportion of iron oxide. This may or may not be a disadvantage, according as the iron oxide is in a fine or coarse state of division. Very finely divided iron oxide acts as a flux, but the coarser iron sulphides (pyrites) which occur in fire clays form coarser grains, which do not have so serious an action on the refractoriness of the clay. Consequently, a brick which is very spotty will probably be more refractory than one which is more uniformly red or brown. The proportion of iron cannot be ascertained from the color of the brick, as a finely divided material will produce a greater amount of color than will coarser particles. Repeated analyses of a well-known brand of fire brick have shown that any attempts to judge the amount of iron from the appearance of the brick is most misleading. As no fire brick are entirely free from iron oxide, any attempts in this direction are necessarily futile.

The quality of fire brick depends largely upon the care exercised in making, burning and cooling of fire brick. The strength falls off rapidly as the temperature increases, hence fabrication defects become quite serious at high temperatures. The need of a severe inspection of open hearth furnace brick is shown by the following figures:

Table No. 55

Tests of Silica Brick Arranged According to Pressures

Pressure Under Which Bricks Were Made, Pounds per Square Inch	Apparent Specific Gravity	Impact Inches	Percentage Spalled	Slag Penetration Square Inches		Expansion Linear Inches Per Foot
				Open Hearth Slag	Heating Furnace Slag	
187	1.50	47	45.5	3.48	2.28	0.155
500	1.58	46	48.3	3.68	2.42	0.155
750	1.59	60	53.2	3.63	2.41	0.158
1000	1.63	65	51.4	3.79	2.42	0.160
1250	1.65	68	47.9	3.65	2.50	0.155
1500	1.66	65	43.6	3.82	2.50	0.160
2000	1.67	67	44.8	3.64	2.45	0.159
2500	1.68	71	42.0	3.72	2.50	0.160

Commercially good brick at 80° F..........2270 lbs. Average Compressive Strength
Commercially good brick at 2450° F..........1170 lbs. Average Compressive Strength
Loss of strength..........48.5% Average Compressive Strength
Defective from fire cracks or poor moulding, etc..........500 lbs. Average Compressive Strength
Loss of strength..........78% Average Compressive Strength

Table No. 56

Losses by Spalling, Expressed as Percentage

Pressure under which bricks were made, pounds per square inch.

Mesh	187	500	750	1000	1250	1500	2000	2500
4	21.9	34.9	37.9	38.7	31.4	30.0	19.1	29.1
8	51.6	45.9	62.6	51.0	43.3	34.8	38.3	43.3
12	62.9	64.0	59.2	64.4	69.1	65.8	67.0	53.6

Table No. 57

Tests of Silica Brick Arranged According to Mesh

Mesh	Apparent Specific Gravity	Impact Inches	Percentage Spalled	Slag Penetration Square Inches: Open Hearth Slag	Slag Penetration Square Inches: Heating Furnace Slag	Expansion Linear Inches Per Foot
4	1.66	57	30.4	3.92	2.63	0.156
8	1.62	63	47.6	3.67	2.39	0.159
12	1.58	64	63.2	3.44	2.29	0.159

Normal working of a 90-ton open hearth furnace using producer gas a silica roof should last on an average, 200 heats.
Furnace roof of "x" furnace after 261 heats lost—20% by spalling.
Furnace roof of "y" furnace after 221 heats lost—23% by spalling.
Furnace roof of "z" furnace after 80 heats lost—47% by spalling.

Clay Fire Brick

Clay brick have in general the same qualities of endurance as silica brick but not to so great an extent. The finer the grinding the more rapid the deterioration.

Table No. 58

Spalling Loss—Clay Brick

Machine made—3 brands Temp. 2450° F.	9% to 27%
Hand made—3 brands—Temp. 2450° F.	7% to 17%
Average burned brick	14%
Hard burned brick	60%
Coarse ground clay brick	8.5%
Fine ground clay brick	50.0%
Drop test of 2½ lb. steel ball on ladle brick—	Breaking height
Temperature 85° F.	51 inches
Temperature 640° F.	40 inches
Temperature 900° F.	34 inches
Penetration test steel ball carrying 1600 lb. load	
Machine made brick—Temp. 2450° F.	.34" Average
Hand made brick—Temp. 2450° F.	.57" Average

Table No. 59

Melting Temperatures of Refractories

	Centigrade	Fahrenheit
Fire Brick—		
Magnesite	2150°	3900°
Chromite	2050°	3800°
Beauxite	1600–1800°	2190–3270°
Silica	1700–1750°	3090–3180°
Fire clay	1500–1750°	2730–3180°
Clays and Sands—		
Chromite $Fe\,OCr_2\,O_3$	2180°	3950°
Bauxite $Al_2\,O\,(OH)_4$	1820°	3308°
Bauxite Clay	1800°	3270°
Silica	1750°	3180°
Silica Sands	1700–1750°	3090–3180°
Kaolin $Al_2\,O_3$, $2SiO_2$, $2\,H_2\,O$	1740°	3160°
Fire Clay	1400–1740°	2550–3160°

All that the color of a fire brick indicates is that, if very dark and spotted, it has probably been burned at a high temperature, and is for that reason better than one which is paler in color, and, therefore, has not been so thoroughly burned. The argument is by no means a sound one, for if two brick are made of the same material, and one has been in a hotter part of the kiln than the other, it will be darker in color, though the actual refractoriness of both brick may be identical. The only value in it lies in the fact that a brick which has been so heated as to develop the iron spots must necessarily be capable of withstanding a similar temperature in use, whereas a pale brick which has not been so intensely heated has its refractoriness unproven, and may, for that reason, be regarded with more suspicion than the other. The view that a "nice-looking" brick is the better for refractory purposes is seldom correct.

Users of refractory materials are sometimes misled by small pieces of a dark, slag-like material on them, and regard these as signs of partial fusion. To a limited extent this is the case, but for most practical purposes these slag-like masses, unless unusually numerous, may be neglected, as they are merely the product of the iron sulphide and the clay, and are generally so isolated as to have very little effect on the brick as a whole. Moreover, they usually occur most extensively at the surface, and an inspection of a broken surface will be much more favorable than that of surfaces ordinarily exposed.

Regenerators of acid and basic furnaces

are alike. Between the ports and regenerators the flues are enlarged, forming slag pockets into which a large percentage of the dust in the gas is dropped due to the decrease in velocity before reaching the checker work. Clay brick is now used for the checker work, whereas 2¾″ square by 9″ long silica brick were formerly used. These, however, did not give good service, as under the scorifying action of the gases they tended to "frit" away. The flue gas dust carrying considerable iron oxide and lime (in basic work) and hence basic in action fluxed and glazed over the surface of the checkers. This reduced the thermal capacity of the regenerators to a serious extent.

Beauxite brick have been suggested for this work. They are very expensive and have a large co-efficient of shrinkage.

Standard open hearth regenerator brick for checkers are 10½″ x 4½″ x 4½″. At the same time it should be said that the so called 9″ straights, 9″ x 4½″ x 2½″ in size are very largely used. Clay fire brick contract on heating. Silica brick expand $\frac{3}{16}$″ per foot under normal furnace temperatures. Chrome and magnesite brick expand when highly heated. The extent of this expansion is shown in diagrams following.

The glazing and scouring of brickwork in the end ports is very severe due to the high temperature and high velocity of dust charged gases. The very best construction is called for to secure long life. To prolong a furnace campaign the expedient of removable ports has met with success. With them there is no shortening of the furnace life as ports may be changed on Sundays. The old ones are then relined, dried and ready at any time for use after a preliminary heating. A number of Wellman furnaces have been so equipped.

In laying clay brick, for the joints, a clay of the same grade as the fire brick should be used. It is best when steamed in the mortar box and used when of the consistency of soup. The joints must be as thin as is possible and secure an even bearing of brick on brick. For silica brick, just enough silica cement is spread on the brick for a joint to eliminate any unevennesses and make a perfectly flat bearing of brick on brick. The expansion allowance is made by slipping in between the brick ends thin slips of wood, so as to secure an expansion of $\frac{3}{16}$″ per foot when the wood burns out, during heating of the furnace.

All arches must have radial joints. As a matter of practical construction, an approximate selection of shapes is best made by drawing the arch to a scale of 1½″ or 3″ to 1′0″, and drawing in the brick by using a combination of side arch brick No. 1 and 2 or wedges 1 and 2 or keys, keeping the joints radial. This is done satisfactorily with the use of generally not over two shapes and the closing is made on the work by driving in place for the key a suitable shape. Forcing the key brick too severely will result in cracking it or the adjacent brick.

These preliminary sketches, of which copies are given to the brick laying foreman, have given great satisfaction in laying the brick, in ordering, and in keeping track during the work of the brick stock needed to complete the job.

Some designers depart from the rigid riveted tie beams over the furnace arch as used in the Wellman furnace by using tie rods, which are tightened or slacked off, by screwing in or out the end nuts. Thus a movement of the arch in heating and cooling is permitted. Allowing the arch to sag the alignment is destroyed. The alignment of the skewbacks is irregularly shifted by the varying amounts by which the nuts are slackened off. The original form of the roof arch cannot be recovered. The resulting varying spans of the roof cause cross shearing or transverse cracks in the roof. The joints open up to the fire and spalling and cracking of the brick becomes a common occurrence and ends in a short life of the roof and furnace. This is prevented by the rigid riveted channel beam ties used in the Wellman furnaces. The expansion causes a slight springing of the arch upwards, which keeps a solid unbroken face of brickwork towards the flame. Roofs of this type have a long life.

Table No. 60 gives the chemical characteristics of the common open hearth refractories and fluxes.

The Refractories Manufacturers Association Specifications, 1919

SILICA BRICK SPECIFICATIONS—DEVIATIONS

On standard or 9-inch and 9-inch series silica brick shapes, and on all special silica brick shapes in what is known as run-of-kiln brick, deviations $\frac{3}{16}$-inch over or under, to each lineal foot thereof, from specified measurements, is allowed manufacturers, these deviations to cover expansion, contraction and warpage. Special prices are made where special silica brick shapes are ordered and sold to follow specifications, these prices being commensurate with the rigidity of the said specifications, and with due regard to all conditions imposed by the said specifications.

CLAY BRICK SPECIFICATIONS—DEVIATIONS

Manufacturers of fire clay brick and shapes insist upon deviations of two per cent from specified dimensions, over and under (covering both shrinkage and warpage) on dimensions of four inches or over. On dimensions under four inches the allowed variations (covering shrinkage and warpage) is three per cent.

These deviations apply to standard 9-inch and 9-inch series shapes and to all special shapes on what is known as run-of-kiln brick.

When special shapes are made to follow specifications furnished by buyers or engineers, prices are based upon manufacturing costs which follow the rigidity and other conditions peculiar to such specifications.

GENERAL INFORMATION AND SUGGESTIONS ABOUT FIRE BRICK

Keep all fire brick in a dry place. Especially in cold weather moisture is highly injurious. Use good clay with which to lay brick, its quality being at least equal to that of the brick.

Use fine ground clay mixed to the consistency of a thin soup. It should be kept well steamed in the mixing box.

In laying brick dip into the clay and rub in place to a brick to brick joint.

Heat brick work slowly. It must be absolutely dried out before being used.

For estimating fire brick use the following figures:

1000 common or red brick will lay up 75 cu. ft. of 12″ wall, having ¼″ joints.

1 sq. ft. of 4½″ wall requires 7 fire brick. Each additional thickness of 4½″ calls for an additional 7 brick.

1 cu. ft. brickwork requires 17 brick 9″ x 4½″ x 2½″ or 9″ straights.

Where keys, wedges and other shapes are used, add from 5% to 10% in estimating the number of brick in 9″ straight equivalents.

9″ straights clay brick weigh 7 lbs. each.

9″ straights silica brick weigh 6.1 lbs. each.

9″ straights magnesite brick weigh 12 lbs. each.

Grain magnesite weighs 148 lbs. per cu. ft.

1 cubic foot of brickwork (clay) weighs 150 lbs.

1000 closely piled fire brick occupy 56 cu. ft. = 17.9 brick per cu. ft.

1000 loosely piled fire brick occupy 72 cu. ft. = 13.9 brick per cu. ft.

For export all refractories must be crated or sacked.

A brick crate of 54 9″ straights will measure 15¼″ x 20″ x 26″.

Table No. 60

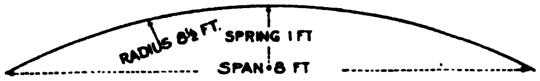
Refractories and Fluxes

	SiO_2	Al_2O_3 & FeO	Al_2O_3	FeO	Fe_2O_3	Fe	$CaCO_3$	CaO	$MgCO_3$	MgO	Cn_2O_3	CaF	P_2O_5	MnO	Alkali or Sulphur	Ignition Loss	H_2O
Chrome Brick	4.16		14.85		15.18			9.0		9.0	46.61					1.25	
Chrome Ore	3.25	24.5			17.5					15.0	40.0						
Magnesite—Raw	0.5 to 2.0	0.5 to 2.0		0.5 to 2.0			50 to 55		40 to 44								
Magnesite—Calcined	2.38		1.46		7.43			4.16		83.68				.30			1.15
Magnesite—Brick	4.57		1.45		4.88	3.15		1.99		86.72				.36			
Dolomite—Raw	.22		.26		1.43			31.34		21.0							.10
Dolomite—Calcined	1.3	1.3		1.3				53.0		43.0							
Graphite—Stopper Graphite—Nozzles	45.95		17.95		3.20			.45		1.06		Graph. 29.39					
Silica Sand	97.25	0.16						.08		.39					.36	.36	.24
Silica Brick	96.22		1.08		.30			2.01		.10						.05	
Syndolag	5.80	6.60						54.0		33.40						.20	
Beauxite	6.00	60.00		4.0													30.0
1st Quality Clay Brick	52.52		42.72		3.21	2.25		.07		.08					1.40		
2d Quality Clay Brick	61.08		34.63		3.79	2.65		.11		.19					.20		
3d Quality Clay Brick	68.86		24.19		4.57	3.20		.12		.33					1.93		
Ladle Brick	65.66		26.87		2.88			.28		3.54						.47	
Moxahala, Ohio Clay	57.08		29.47	1.21				.30		.29					.45	3.43	9.51
Clearfield, Pa. Clay	48.35		36.37	2.0				.07		.12					2.54	4.73	10.56
St. Louis, Mo. Clay	57.13		27.89	1.99				.66							.68	4.40	10.54
Woodbridge, N. J. Clay	67.84		21.83	1.57				.28		.24					2.24	4.33	5.90
Acid O. H. Slag	49.40			29.80													
Basic O. H. Slag	11.00	1.6		22.0				44.0		6.6			5.6	9.0			
Basic O. H. Slag	.33			10.9				39.75					5.8	9.0	0.08		
Mill Cinder	19.58					55.06							4.2		0.21		
Roll Scale																	
Limestone	.2 to 1.0	0.5 to 2.0					95 to 99		0.5 to 1.0								
Fluor Spar	0 to 1.0	0.5 to 1.0										90 to 98					

Clay in sacks 24″ x 16½″ x 7½″ will contain 200 lbs. of clay.

To Find Diameter of Circle, Given Size of Brick

Multiply length of brick by 2; multiply this product by size of brick on small end, then divide by the difference between large and small ends of brick.



To find diameter of circle this key brick will turn:

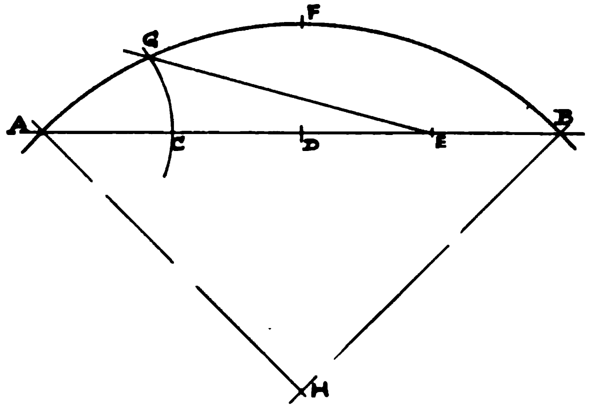
Length, or 9 in. x 2 = 18

18 x 3½ = 63

63 divided by difference between large and small ends (4½ – 3½ = 1) = 63 inches or the diameter.

To Find the Length of an Arc, when the Span and Rise are Given

Divide the chord into 4 equal parts. With one extremity as a center, take distance to the first quarter as a radius and intersect the arc. The distance from this intersection to the third quarter of the chord is equal to ½ the arc length.



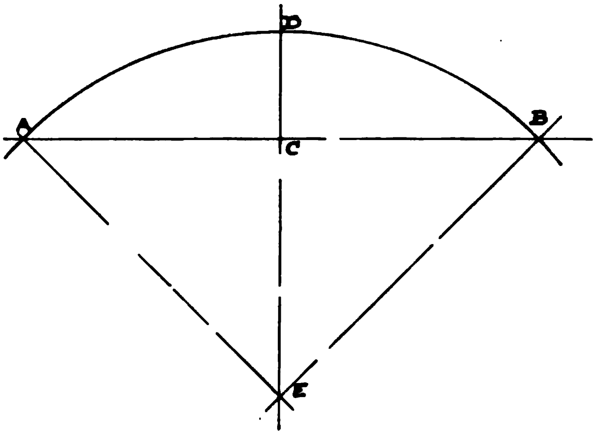
AB = CHORD
AC = CD = DE = EB = ¼ CHORD.
GE = ARC AF = ARC FB

How to Find Radius of Circle, Given Span and Spring of Arch

To square of ½ of span, divided by spring, add the spring and divide by 2; result is the radius of circle.

EXAMPLE

Span – 8 ft.
To find radius:
Spring – 1 ft.
½ of 8 = 4, squared = 16
16 divided by spring, or 1 = 16
add spring 1
17
divide by 2 = 8½ or radius.



AB = SPAN = 8'-0"
DC = SPRING = 1'-0"
½ SPAN = 4'-0"; 4^2 = 16.0
RADIUS = AE = $\frac{16+1}{2}$ = $\frac{17}{2}$ = 8'-6"

CHAPTER XVII

Hot Metal Mixers

The most economical handling of hot pig metal is by direct transfer from the blast furnace to the steel furnaces or converters. Owing to the irregularity in the composition from cast to cast, or even in the metal of a single cast, the best practice is for the blast furnace iron to be poured into a hot metal mixer, from which iron of a reasonably uniform character and temperature is drawn for the steel mill.

Mixers are built of a capacity ranging from 100 tons up to 1500 tons capacity. There is little loss of heat as the vessels are completely enclosed—even to having lids for the receiving and pouring spouts while the thick fire-brick lining is an adequate heat retainer. Nevertheless auxiliary heat of burning oil or producer gas over the surface of the metal is provided. The cooling of the iron, in transit from the blast furnaces, is more than offset, and a uniformity is secured of temperature of metal withdrawn from the mixers. An advantage in the use of mixers is the improvement in composition of the metal. A considerable amount of the graphitic carbon separates from the iron and appears on the surface in the form of flake graphite or "kish." Silicon is reduced and a part of the wear on the furnace hearths saved. A certain amount of dephosphorization and desulphurization occurs also. The net result is to give to the open hearth furnaces a metal partly refined, working faster in the mill, with less fuel and operating cost and decreased refractories repairs. It may be said that to a limited extent the mixer takes the place of and performs the functions of the first furnace of the Bertrand-Thiel process.

By using a mixer (capable of being heated) and carrying out but a small amount of refining in the same, the production of steel furnaces supplied by it can be largely increased.

At some plants the elimination of the metalloids is on a scale sufficient to approach the action of the Talbot furnace.

A fully equipped mixer plant should be furnished with heat regenerators to economize use of auxiliary fuel.

The following items should be considered in deciding upon the use of a mixer.

1. A mixer of 500 to 600 tons is appropriate for a plant of moderate size.
2. The arrangement of the mixer should be such as to receive and discharge metal most conveniently suited to the manner of its transportation from the blast furnaces and delivery to the open hearth furnaces.
3. The mixer should be located as near to the open hearth furnaces as possible.
4. In figuring the size of the mixer, liquid cast iron is taken as weighing 426 lbs. per cubic foot.
5. While some suggest an arrangement in which the receiving ladle for the mixer is put in a pit on the pouring side, this should be avoided by all possible means. Splashing or spilling of hot metal when coming in contact with pools or puddles of water has caused most serious ex-

plosions, resulting in loss of life and disorganization of the shop routine. To the claim that water should not be present, it is well known that it is freely used, especially in hot weather to cool off the surroundings of the furnaces and mixers.

Table No. 61

Hot Metal Mixer Operation

Report of Two Week's Run

No Operation from Saturday noon until 2 A. M. Monday

INPUT:		
Blast furnace hot metal	28,597,550 lbs.	95.64%
Cupola remelted metal	1,295,085 lbs.	4.33%
Mixer spout scrap from previous week	9,000 lbs.	.03%
Total	29,901,635 lbs.	100.00%
PRODUCT:		
To Bessemer mill	29,157,500 lbs.	97.52%
Skulls in blast furnace direct metal ladles	301,200 lbs.	1.00%
Skulls in cupola ladles	3,815 lbs.	.01%
Skulls from mixer spouts	145,620 lbs.	.49%
Scrap	71,208 lbs.	.24%
Balance left in mixers	7,000 lbs.	.02%
Total	29,686,343 lbs.	99.28%
Loss	215,292 lbs.	0.72%
Total	29,901,635 lbs.	100.00%

The item of loss covers the elimination of graphite carbon in the form of "kish," and a certain amount of desiliconization of the iron and other incidental losses.

Mixers of small size are usually emptied at the end of the week's run, closed and heated with oil or gas. Mixers of large size are more advantageous as they are used to take and hold the entire blast furnace output of hot metal over the week end. Such mixers are oil or gas fired and equipped with regenerators.

It may be of interest to give the approximate weight of material for a 500-ton mixer installation:

Table No. 62

Weight of a 50-Ton Mixer

	Hydraulic Control	Electric Control
Weight of Castings.....	503,000 lbs.	515,000 lbs.
Weight of plate and shapes..............	164,000 lbs.	165,000 lbs.
Size of control.........	24" dia. cylinders	200 H.P. Motor
Brickwork.............	46,000 brick	46,000 brick

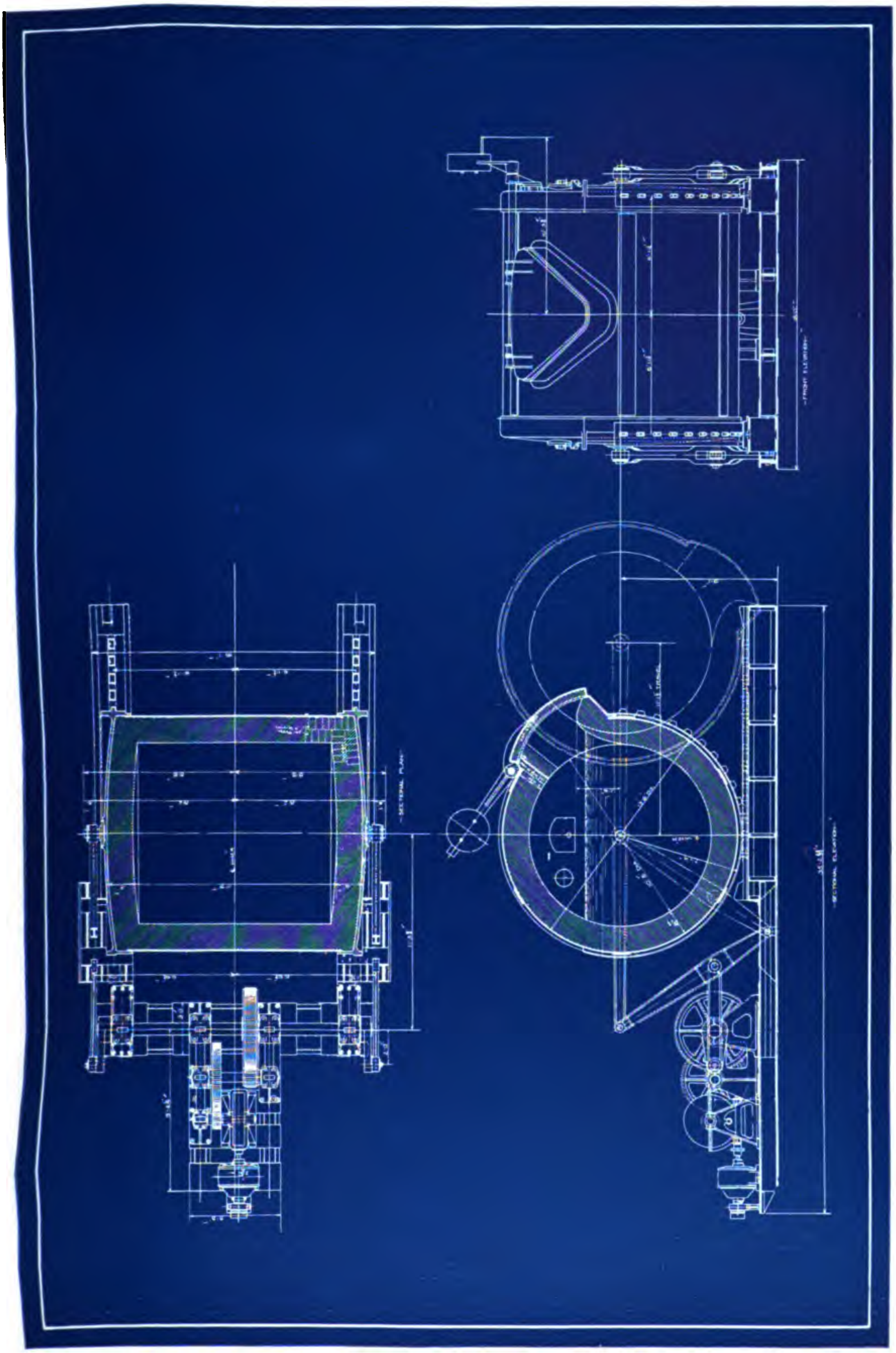


Figure 83—150-TON WELLMAN ELECTRIC TILTING HOT METAL MIXER

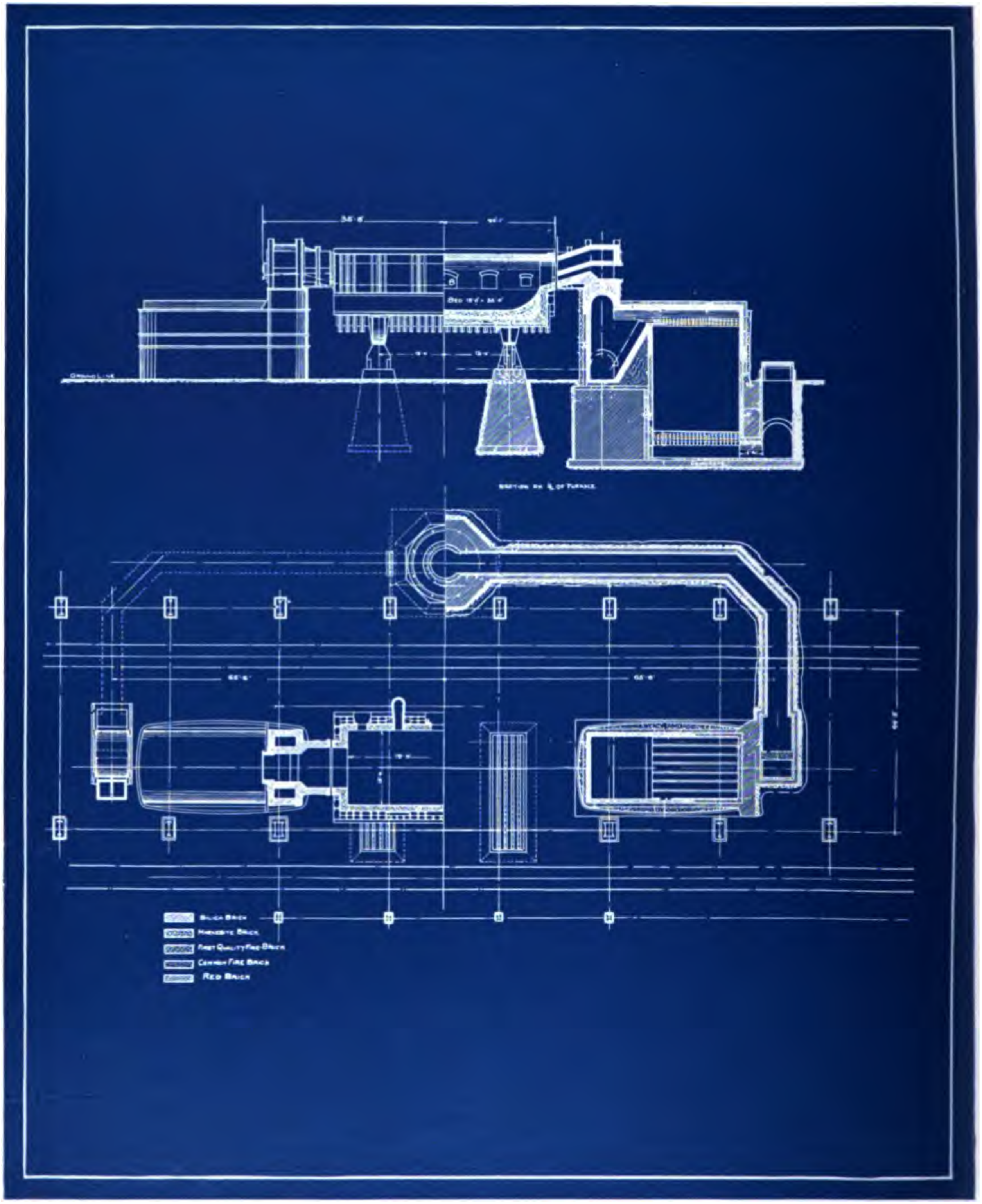
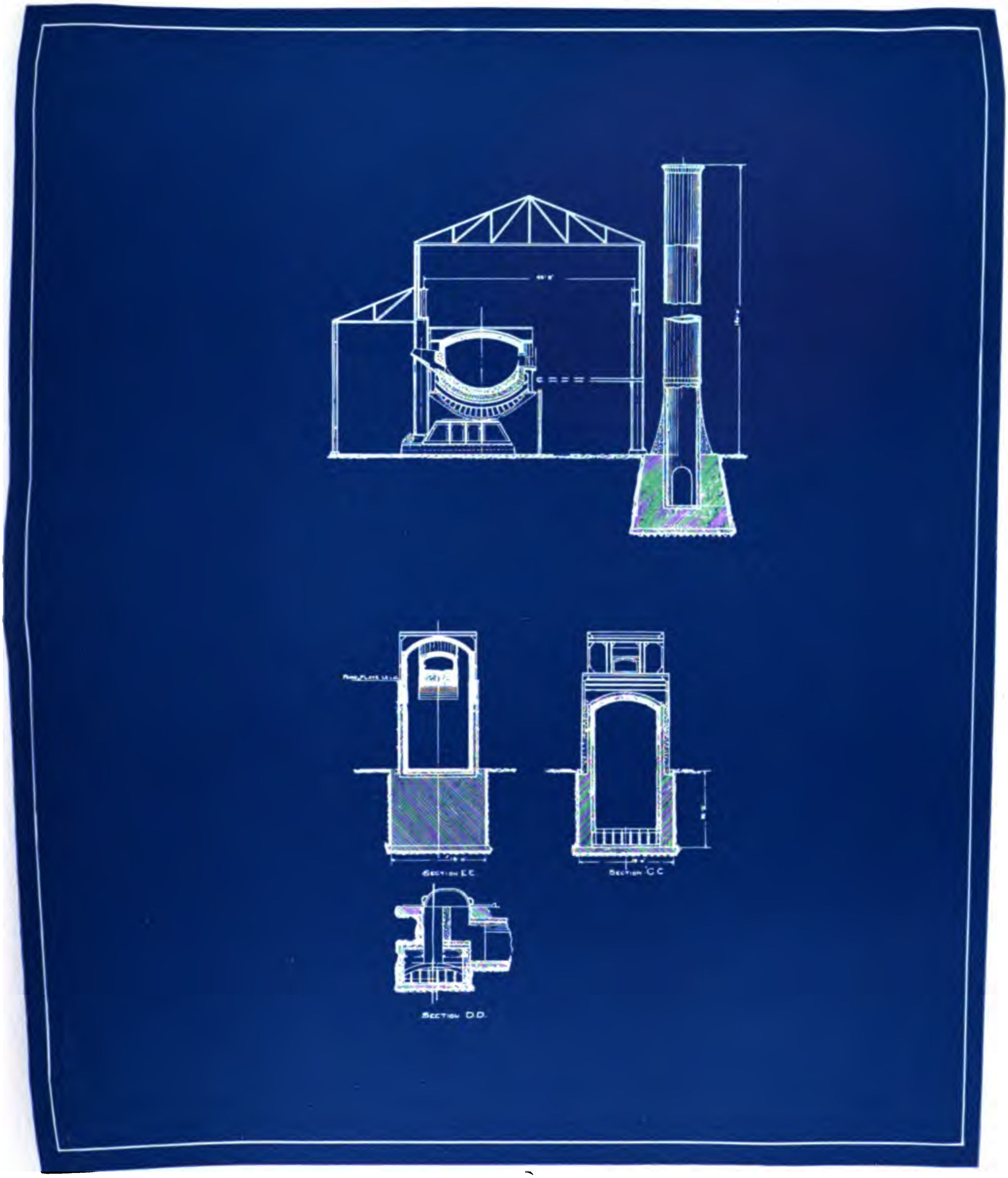


Figure 84—200-TON BASIC LINED WELLMAN HOT METAL MIXER OR STORAGE FURNACE

This furnace is designed on the lines of an open hearth furnace. Bed 15 feet by 38 feet.



Area 570 square feet. Area per ton of capacity 2.85 square feet. Regenerator 24 feet high, 17 feet long, 12 feet 2 inches wide. Volume 2044 cubic feet.

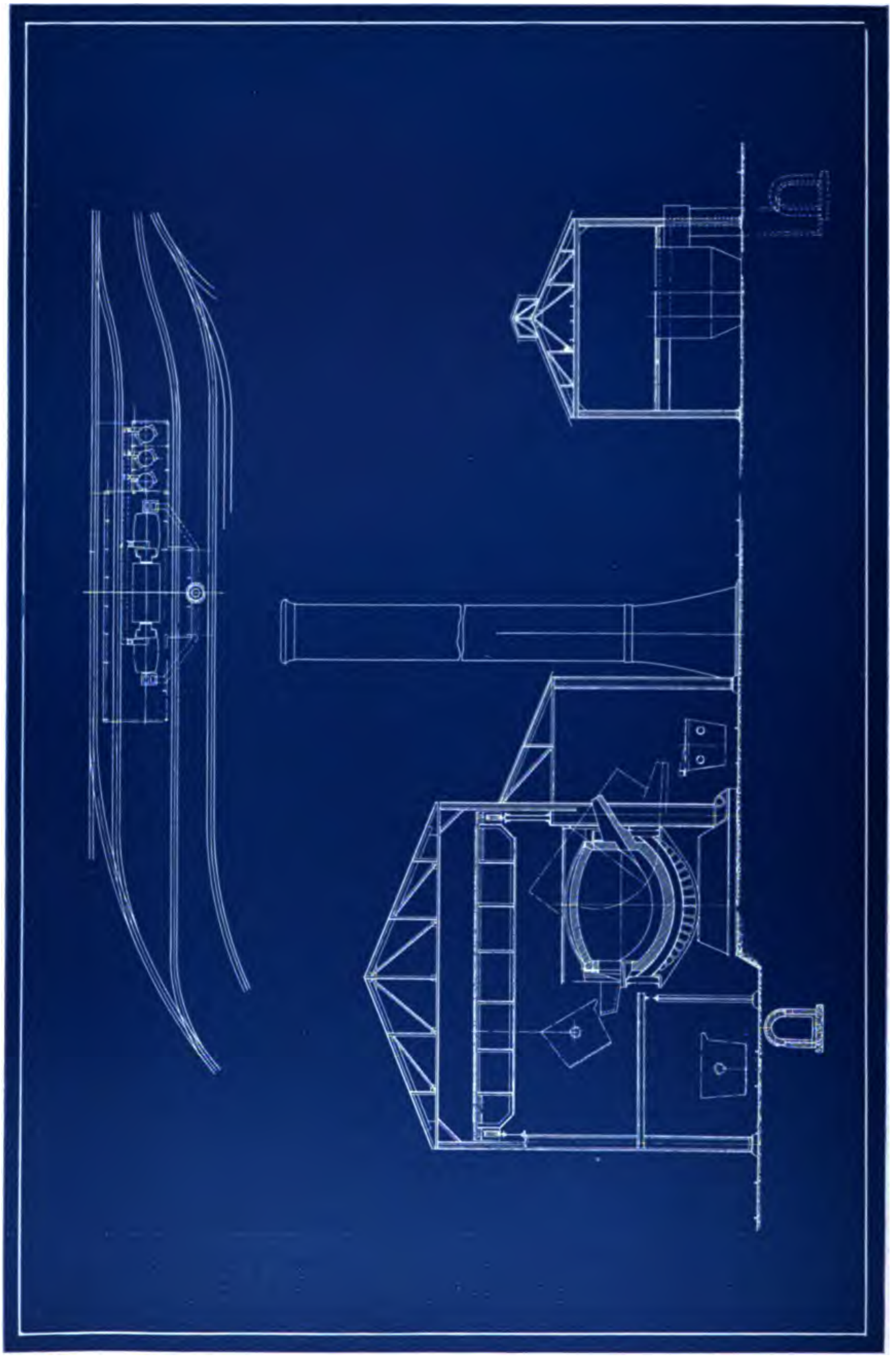


Figure 85—200-TON WELLMAN HOT METAL MIXER

Built for the Tennessee Coal, Iron & Railway Co. This mixer is heated with producer gas. A mixer taking iron from a number of blast furnaces delivers hot metal to the steel mill of practically constant quality.

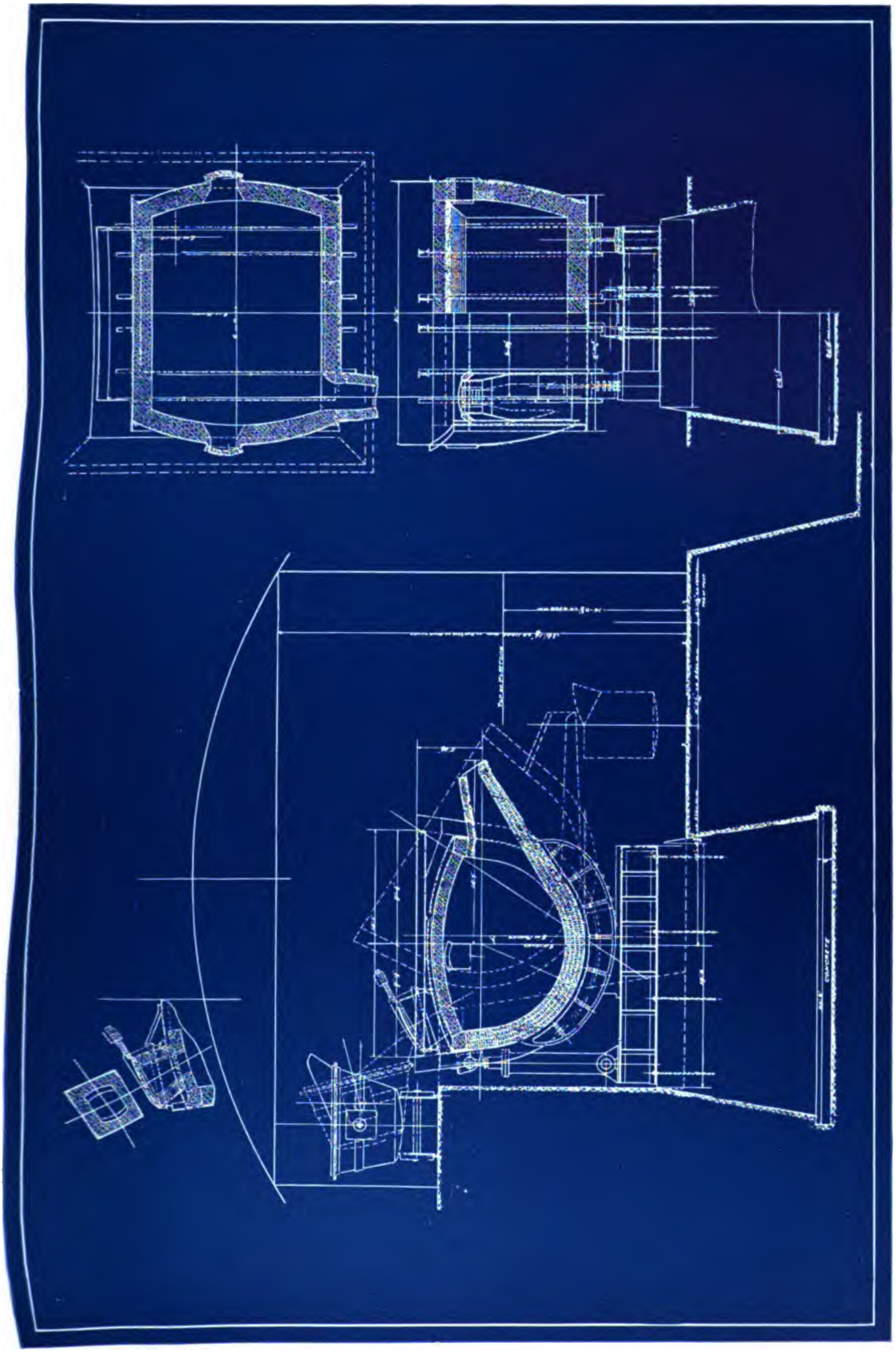


Figure 86—250-TON WELLMAN HOT METAL MIXER
This mixer is arranged to be heated with oil. This mixer was built for the Japanese Imperial Government.

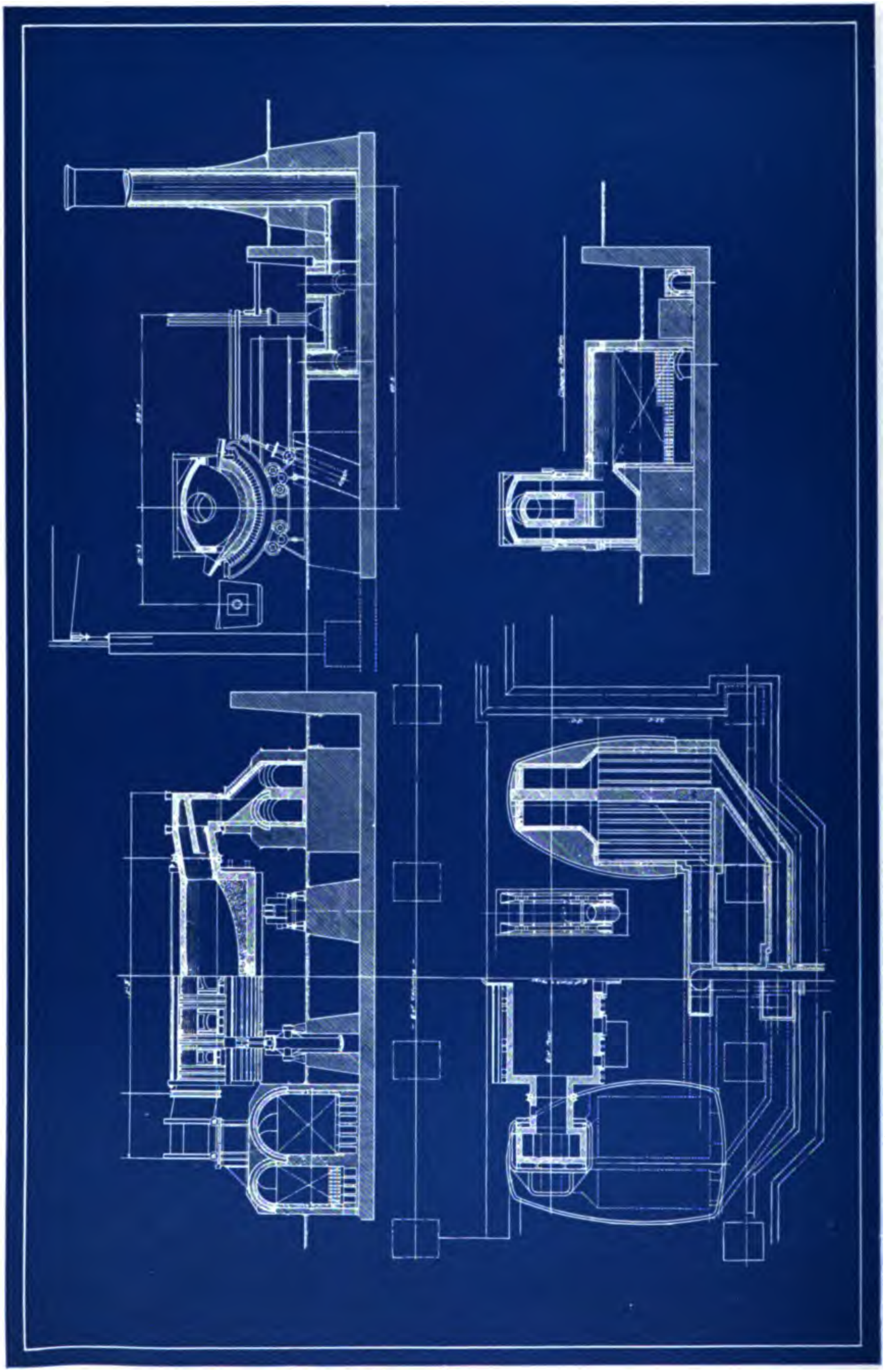


Figure 87—250-TON WELLMAN HOT METAL MIXER

Built for the Glengarnock Iron & Steel Co. of Scotland. Producer gas fuel. Hydraulic operation. Bed 15 feet 0 inches by 38 feet 0 inches. Stack 6 feet net diameter and 150 feet high.

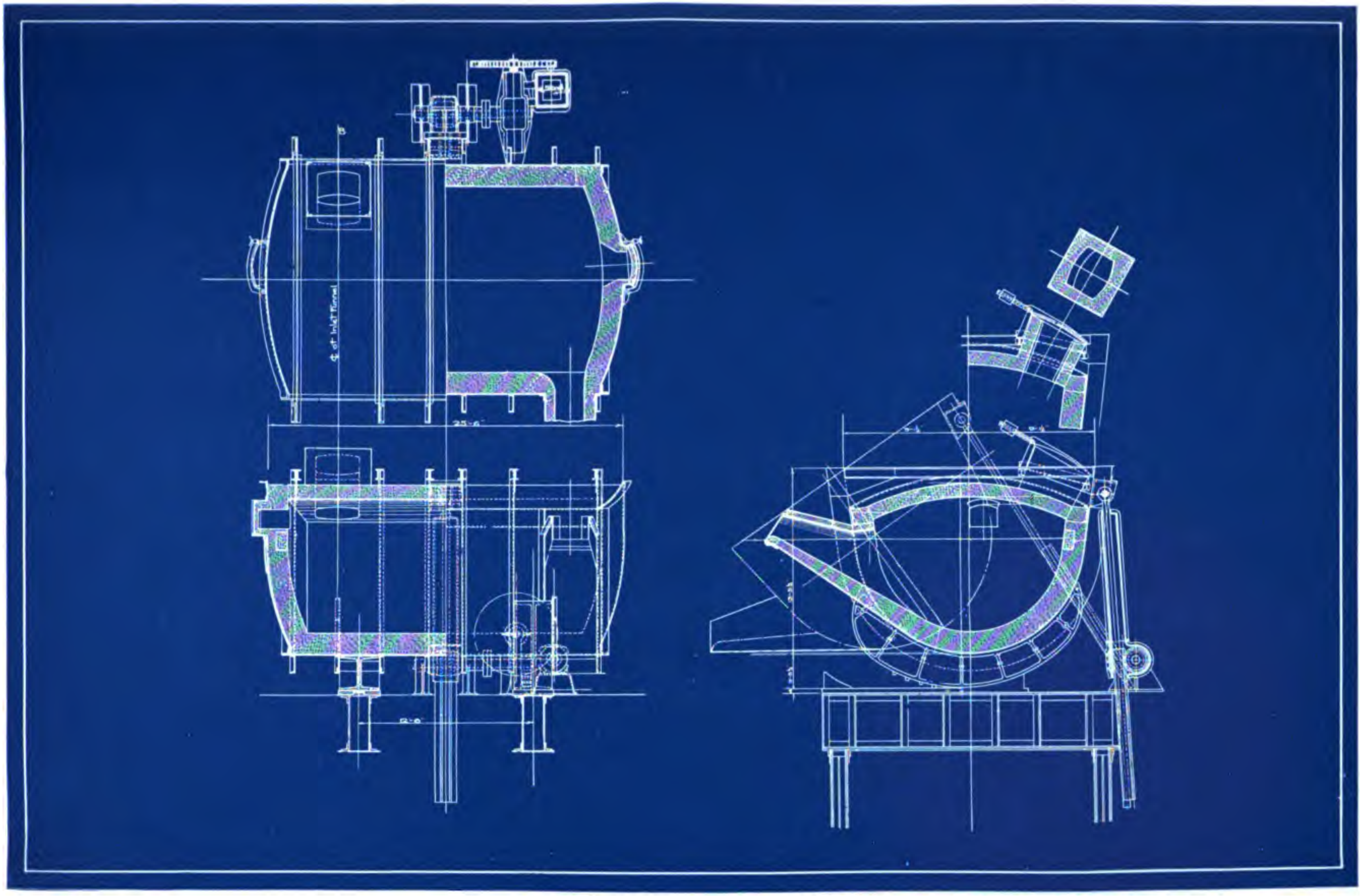


Figure 88—300-TON WELLMAN HOT METAL MIXER

Bed 6 feet 9 inches by 22 feet 6 inches. Area 152 square feet. Area per ton 0.5 square feet. This mixer was built for the Lackawanna Steel Co.

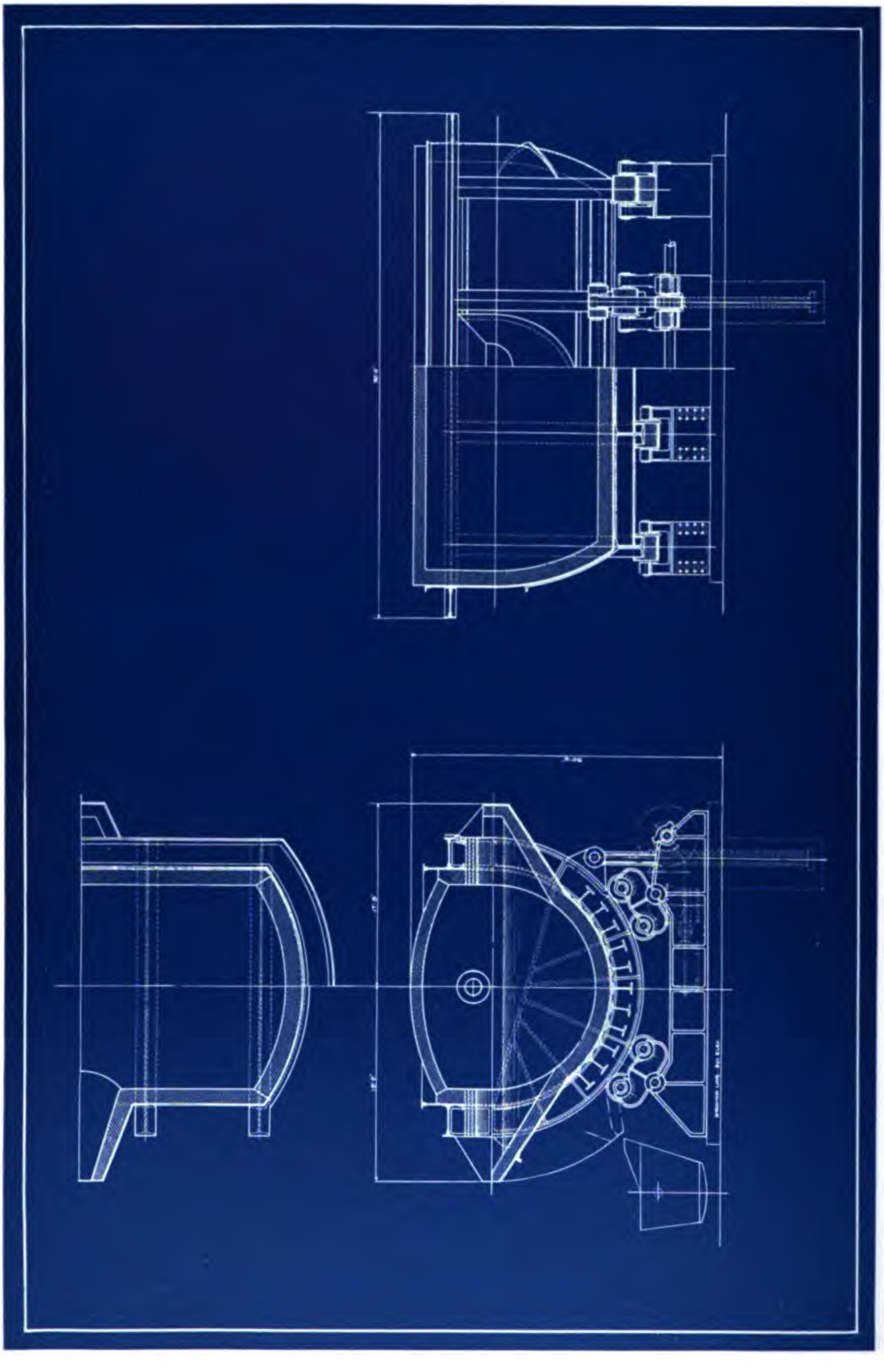


Figure 89—1000-TON WELLMAN HOT METAL MIXER

Gas or oil fuel without regeneration of waste heat.

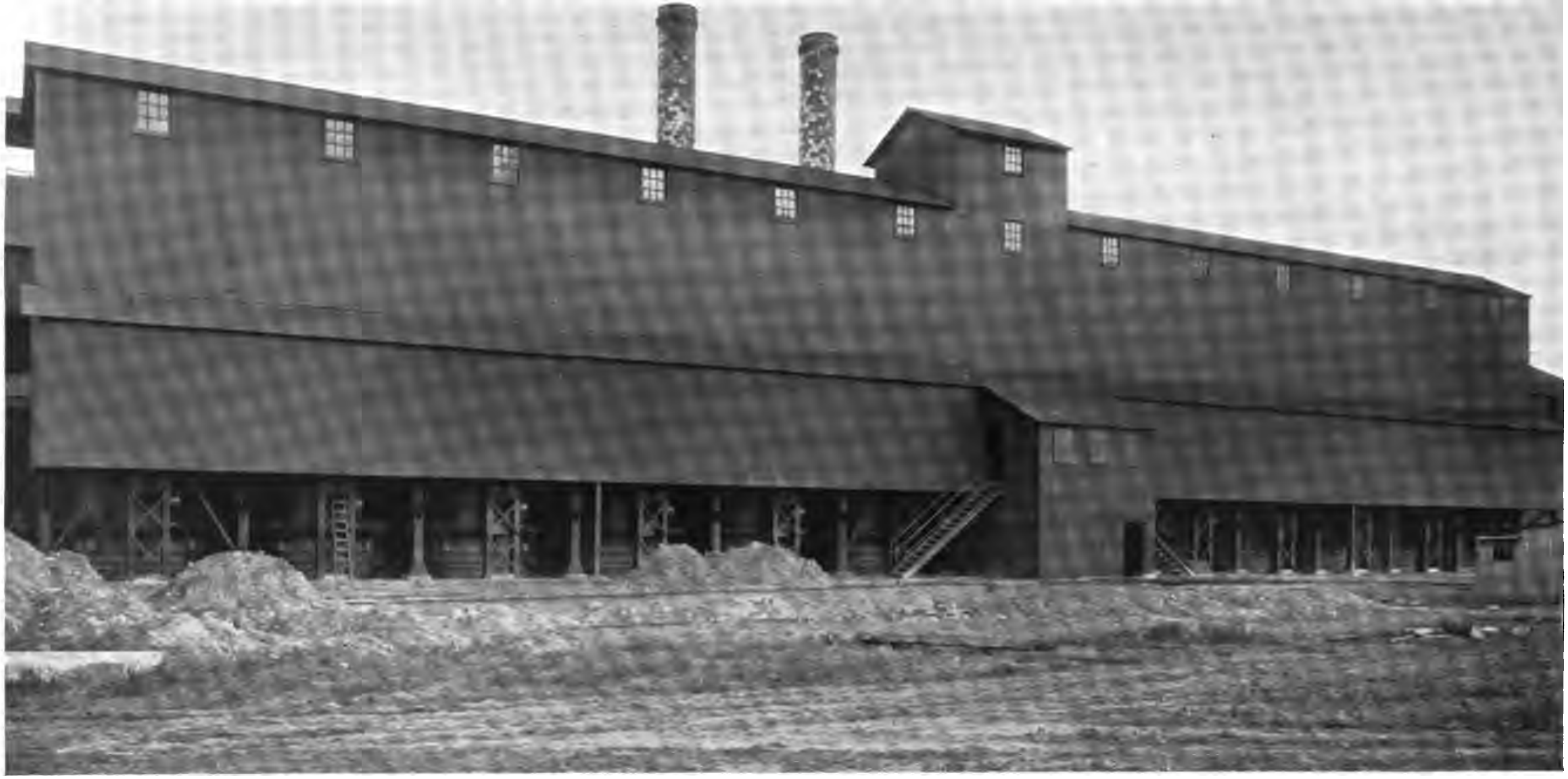


Figure 90—GAS PRODUCER BUILDING

Housing a battery of twelve Wellman (Hughes) gas producers at the works of the American Zinc Company of Illinois at East St. Louis, Ill.

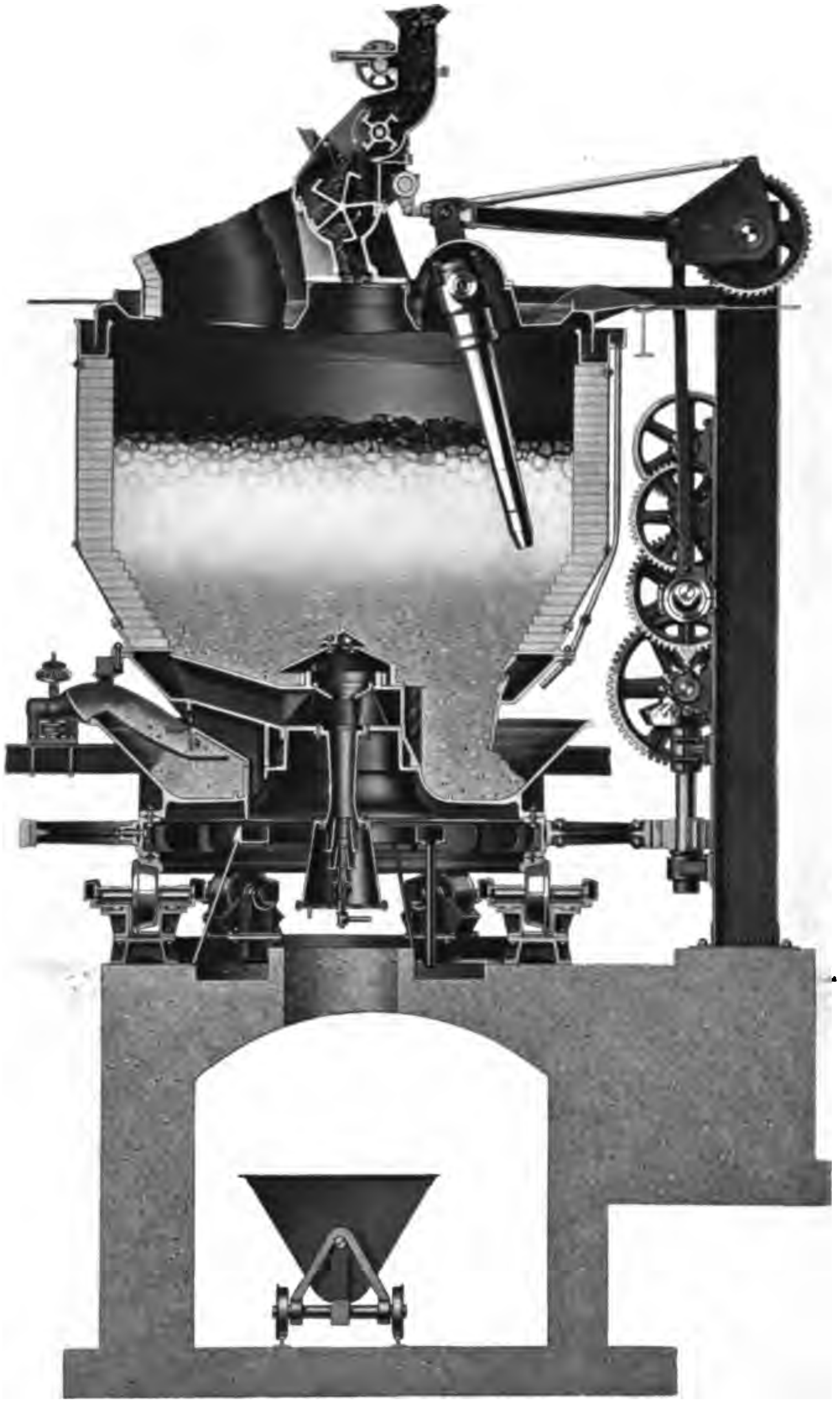


Figure 91—CROSS SECTION OF A WELLMAN (HUGHES) GAS PRODUCER

The entire operation of coal feeding, fire poking, ash removal, blast supply is mechanical and the care of the fire is automatic. Gas of a rich uniform quality is made as the poker prevents formation of holes, or caking accretions of the partially distilled coal.

CHAPTER XVIII

The Wellman Mechanical Gas Producer

Producer Gas

Any gas supply to be satisfactory must not only be adequate but also dependable. There must be a uniform quality of gas and a steady and constant supply. Producer gas fulfils these requirements and, for industrial and metallurgical purposes, its advantages have been demonstrated in competition with all other fuels.

Producer gas is a mixed gas. Its manufacture is a combination of distilling and burning processes, the elements being fuel, air and steam. The accurate control of these three factors is essential for successful operation.

In the Wellman producers, the fuel is fed in at the top and passes through four stages.

1. At the top of the producer is the green fuel.
2. Next below is a zone of partially distilled or decomposed fuel.
3. Next is an incandescent zone in which the burning fuel generates high heat. The burning is controlled by the amounts of steam and air blown. If air alone were blown, there would be complete combustion in this zone with no production of fuel gas, resulting in rapid destruction of the producer. The steam dampens the intensity of combustion, decomposes into hydrogen and permits the formation of CO.
4. The fourth zone is ash, the mechanical removal of which is an important feature of the Wellman producer.

Slow, steady, sufficient feeding of fuel and proper uniform combustion, controlled by the injection of correct amounts of air with steam are necessary to give correctly mixed gas.

Theoretically any carbonaceous material, such as sawdust, lignite, peat, coke breeze, or straw, may be gasified, but commercially, coal or coke is used, as these fuels are more easily obtained and apparatus for gasifying them is less costly to install and maintain. A mixture of coal and coke has been successfully used.

Wellman Record

The first Hughes mechanically poked continuous gas producer was built in 1897 for the Pencoyd Iron Works, Pencoyd, Pa. This producer is still in operation.

After the original installation was built, the Wellman-Seaver-Morgan Co. obtained the rights to manufacture the producer. Since then it has been an exclusive Wellman product.

Over one thousand Wellman gas producers have been installed in the United States and foreign countries. Fourteen installations have batteries of twenty or more and one user has one hundred and nineteen.

Design of Wellman Producer

The illustration on page 208 gives a good idea of the design and principle of operation of the Wellman gas producer. It consists of a revolving chamber in which the fuel is decomposed, operating mechanism, a mechanical poker, fuel feeding device, ash remover, and blower.

The Combustion Chamber

The combustion chamber is a cylindrical plate steel shell—the lower part tapering toward the ash-pan. This shell is lined with fire-brick.

Operating Mechanism

The producer shell is bolted to a cast iron base ring and supported by a three-arm cast steel blast spider, to which is bolted a cast iron water-seal, forming an ash receptacle. The base ring rests upon supporting columns bolted to a cast iron revolving turn-table. This turn-table has at its outer circumference a cast iron gear into which meshes a spur pinion keyed to a vertical shaft and connected to the main driving shaft by a train of gearing; thus the turn-table is rotated, and with it the body of the producer and the ash-pan. The bottom of the turn-table is fitted with a steel tread resting on six chilled iron conical carrying wheels supported by the necessary axles and boxes.

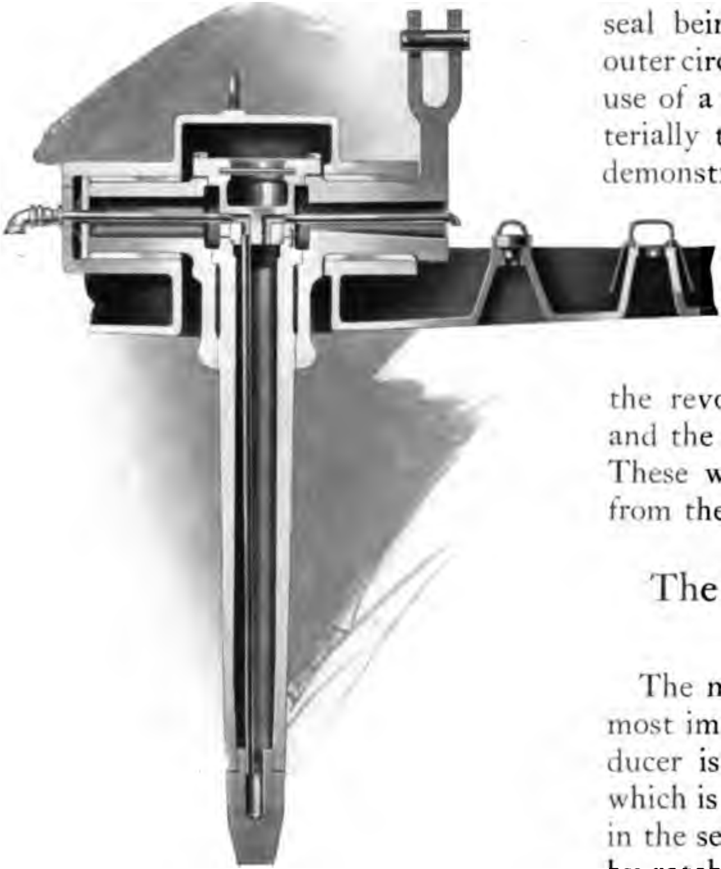


Figure 92—Cross Section of Wellman Water Cooled Mechanical Poker of the Wellman Gas Producer.

Spur and bevel gears give the proper ratio of speed from motor to producer.

The main shaft and gearing are supported by a steel framework securely braced to the top of producer. The gearing is accessibly located.

The cover of the cylindrical shell is stationary. It is a steel casting flanged and ribbed to provide for water-cooling, a water-seal being formed by a top flange at the outer circumference of the producer top. The use of a steel casting for this top adds materially to its durability, as experience has demonstrated that where parts are exposed to the heat, steel castings are superior to cast iron. The top holds a large quantity of cooling water. Water-seal chambers between the stationary top and the revolving shell and between the shell and the ash-pan prevent the escape of gas. These waterseals are filled by the overflow from the receptacles in the cover.

The Water Cooled Mechanical Poker

The most characteristic and perhaps the most important feature of the Wellman producer is the mechanically operated poker, which is suspended from trunnions as shown in the sectional view. The poker is operated by ratchet gearing actuated by a crank and crank shaft which is driven by a reduction gearing connected to the main shaft.

The arrangements of the rotating and poker mechanisms on the machinery column makes the bearings easily accessible and gives a rigidity which tends to keep the bearings in perfect alignment. All gearing in which operators might be injured if it were left exposed is protected by sheet steel guards.

The poker is water-cooled and it is suspended from the cover and extends into the fuel mass penetrating through the green fuel zone into the zone of incandescent fuel. It is actuated by the driving mechanism and swings back and forth in a vertical plane as the mass of fuel revolves. The path of the poker, from the center to a point a few inches from the brick lining of the shell, describes a series of loops as shown by the diagram.

By this combined action, the soft, partly-decomposed fuel above the incandescent zone is prevented from caking. The gas is liberated and the incandescent zone itself is kept free from clinkers so that the fuel descends positively toward the ash-pan.

Hand labor in poking is eliminated; moreover, the fuel is not subjected to the variations in treatment incidental to hand poking. The uniform treatment secured by the mechanical poker has proven extremely beneficial, giving better and more uniform results as to quality, quantity, and supply of gas, and reducing the cost of installation and operation of plant required for a given capacity.

Gas fuels in the process of gasifying tend to form a pasty mass, which, if not broken up, makes a seal through which the gas cannot escape freely. Clinkers, if they are allowed to form, also interfere seriously with combustion and prevent the proper progress of the fuel downward from the top toward the ash-pan.

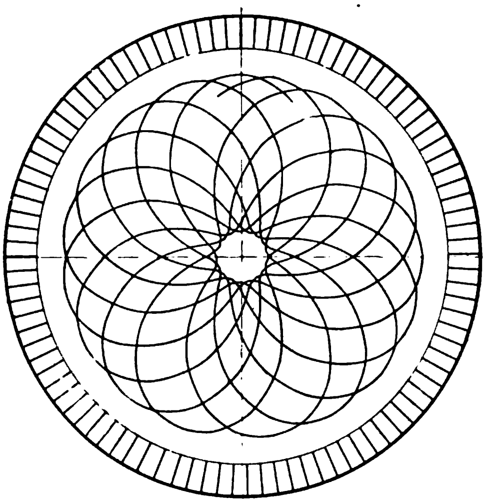


Figure 93—Path of the Poker in the Fire During Twelve Revolutions of the Wellman Producer

The Wellman mechanically-operated poker stirs the fuel mass constantly and prevents either of these difficulties from interrupting the steady production of a rich gas. It is one of the distinguished features of the Wellman machine and has had much to do with its tremendous sale and unquestioned superiority.

Seven Hughes Mechanical Gas Producers for Otis Steel Co., Cleveland

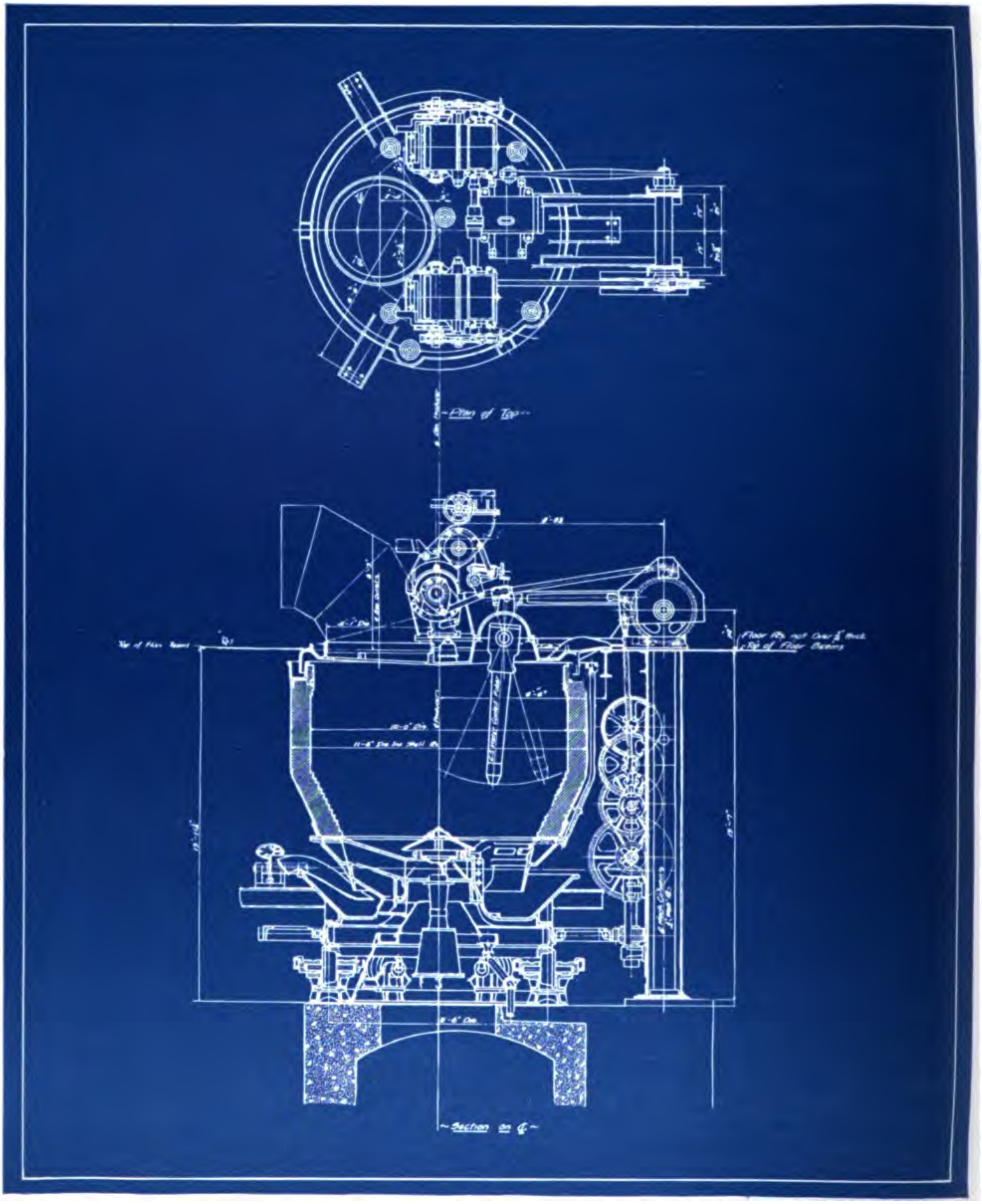
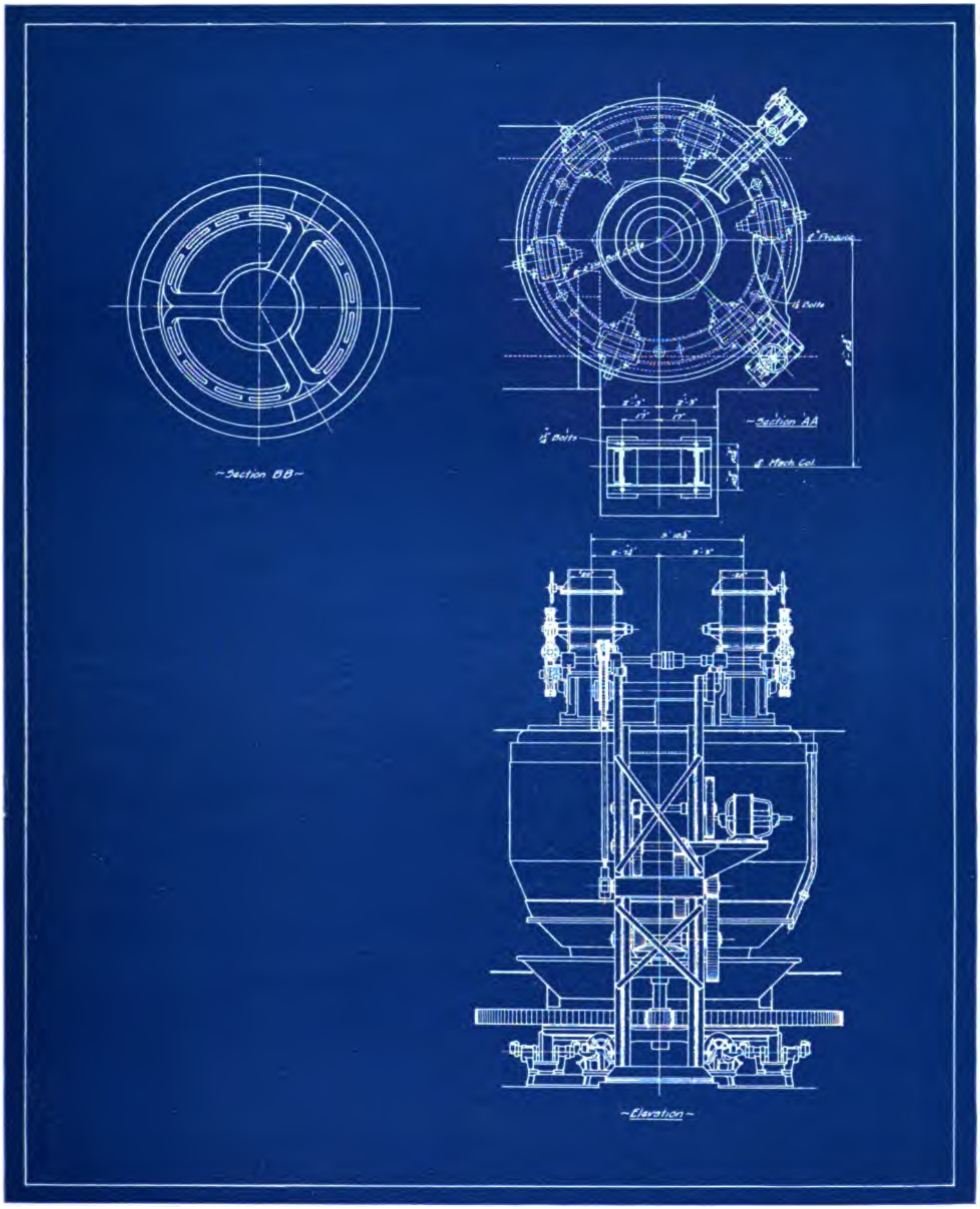


Figure 94—GENERAL DRAWING OF WELLMAN GAS PRODUCER

This producer consists of a revolving combustion chamber in which the fuel is decomposed, operating mechanism, a mechanical poker, fuel feeding device, ash remover



and blower. The combustion chamber is a cylindrical plate steel shell—the lower part tapering toward the ash-pan. This shell is lined with fire-brick. The mechanical poker eliminates hand labor. One gas man with two laborers can operate six producers.

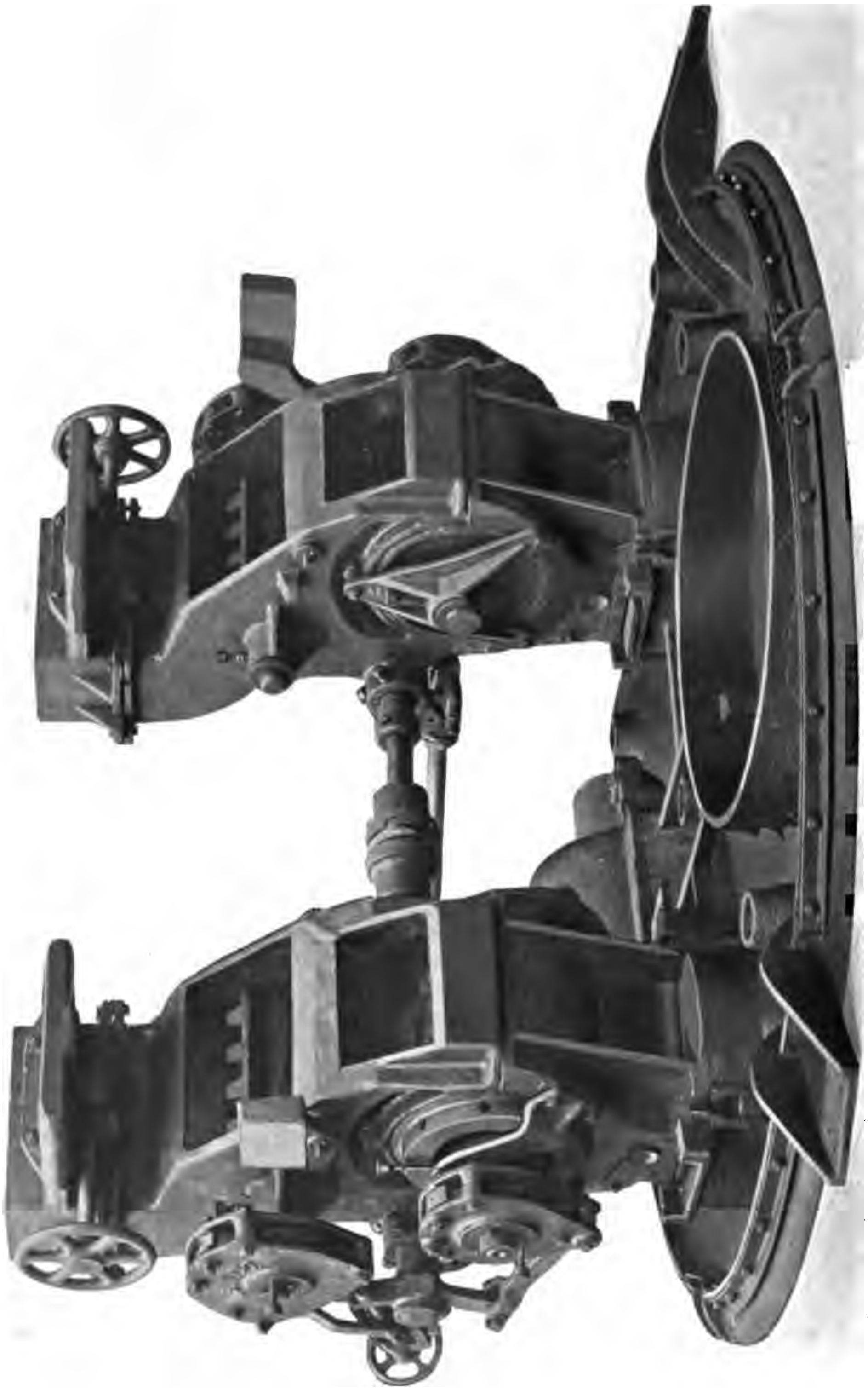


Figure 95—THE WELLMAN MECHANICAL COAL FEED

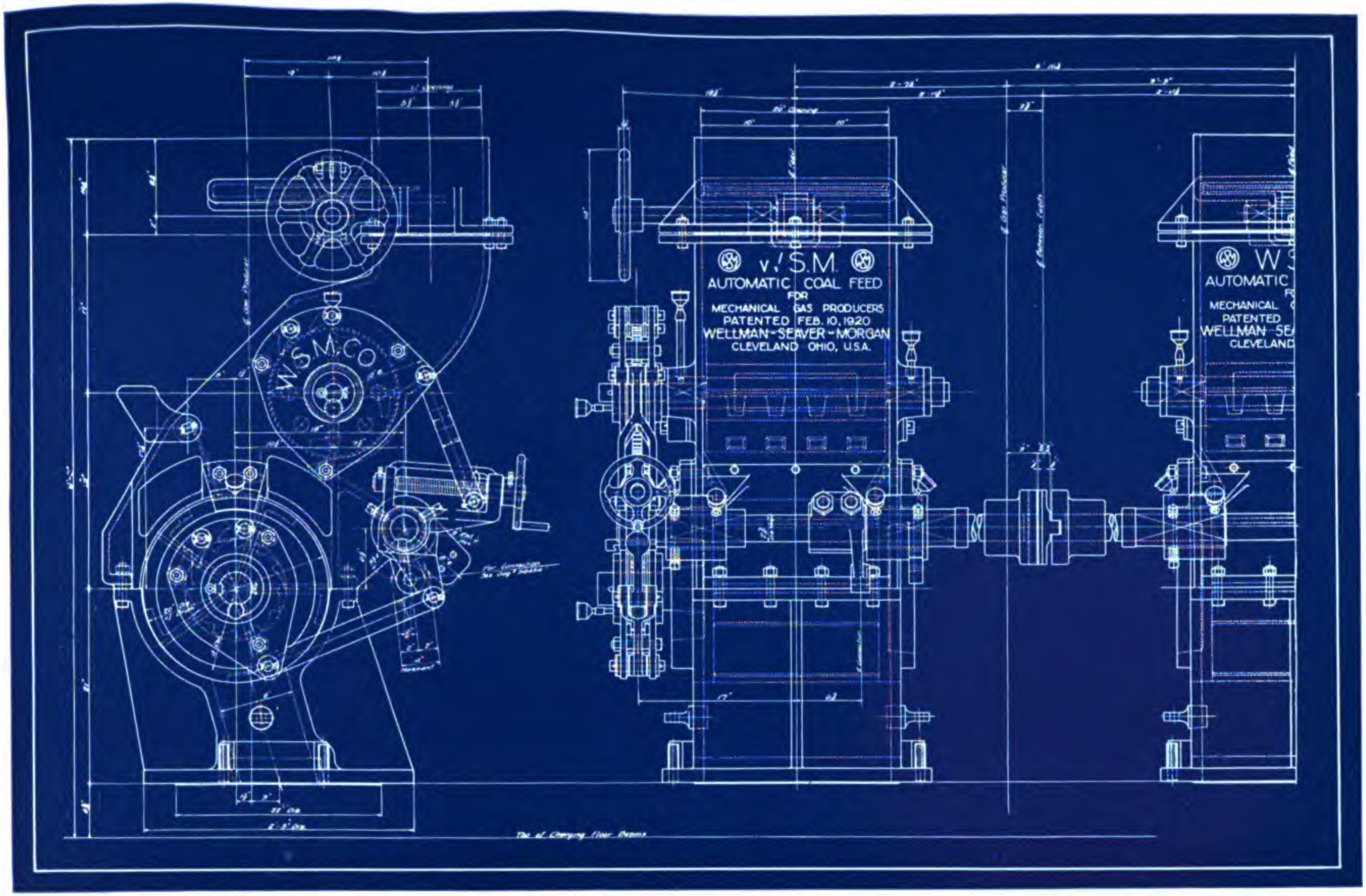


Figure 96—MECHANICAL COAL FEED OF WELLMAN (HUGHES) GAS PRODUCER

Coal is fed into the producer and distributed so as to give a constant flow of coal proportional to the rate of gasification. The mechanism is of a strong rugged construction and open for inspection.

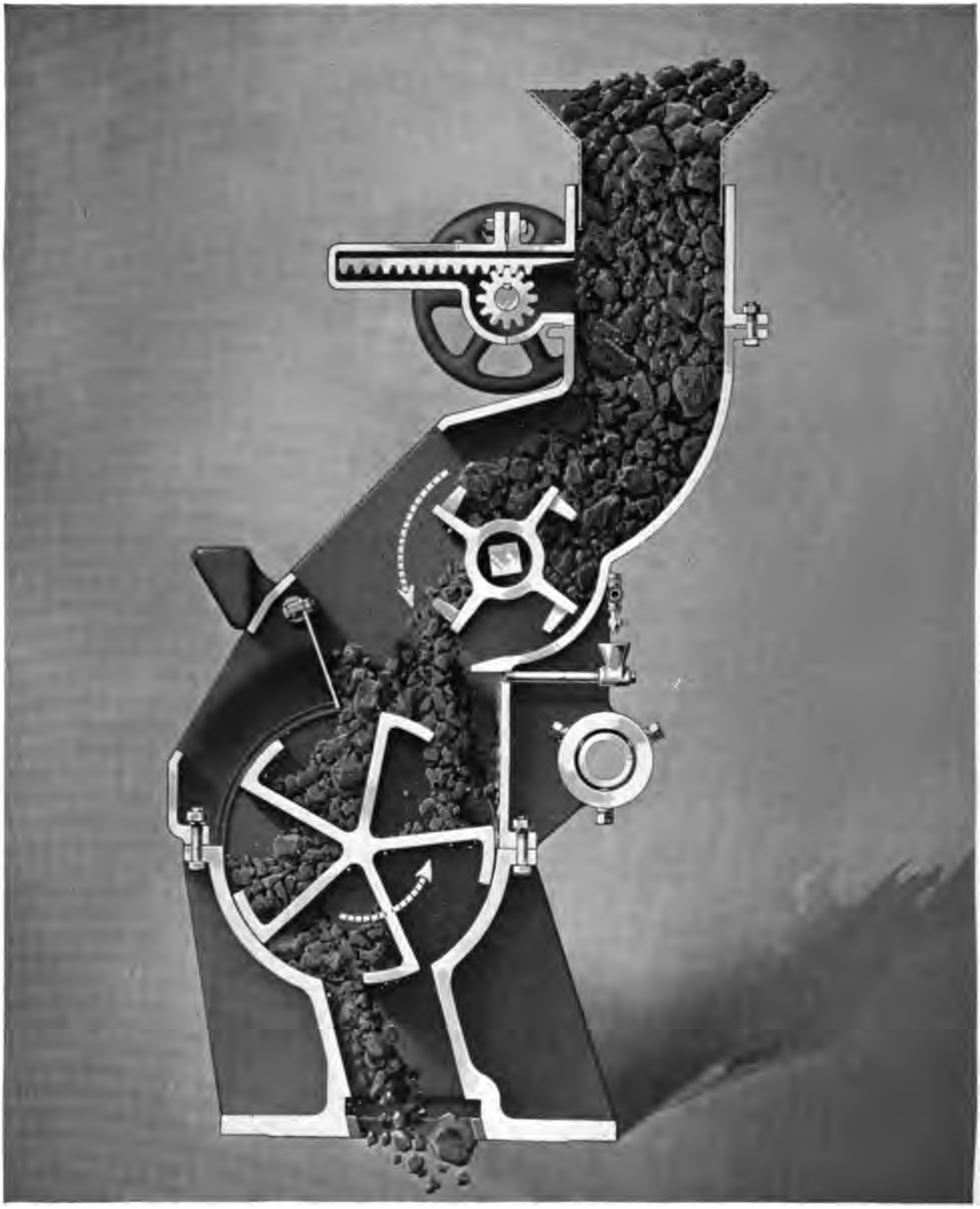


Figure 97—CROSS SECTION OF WELLMAN MECHANICAL COAL FEED
Showing the flow of coal into the producer and the water drip lubricator.

Mechanical Coal Feeds

The Wellman mechanical gas producer is fitted with a set of two Wellman heavy duty mechanical coal feeds. The two feeds are placed on the top plate at different distances from the center.

Each feed consists of two elements. The first is the measuring wheel—a variable speed four-arm vane—regulating the amount of coal discharge. The other element is a five pocket feed valve, revolving at a constant speed in a machined seat. This device feeds the coal at a speed proportioned to the rate of gasification. At the same time it prevents gas leakage. For every 9½° of rotation of the producer, coal is discharged from each feed. As the feeds discharge alternately there will be a discharge of coal every 4¾° of revolution. This insures a practically continuous flow of coal into the producer.

The upper measuring wheel revolves in an upward direction with reference to the main body of the fuel. This lifting or shoveling effect keeps the down-coming coal loose and free from packing tight in the downtake.

Grinding or crushing of the coal is avoided and a positive feed regulation is obtained dependent upon the speed of the measuring wheel. Nor does grinding or crushing occur on the upper half of the measuring wheel, as clearance is provided between the wheel and the case.

The case has large openings for inspection and for the removal of foreign matter. Every part of the feeds is entirely accessible. Should it be necessary to take out any part above the valve seat, this may be done without disturbing the balance of the feeder. A clay or sand sealed damper in the valve seat casting will shut off the feed from the producer when closed. With this arrangement it is possible to shut off the gas from a feed unit and take out the lower feed valve. This operation may be accomplished by the removal of two bolts and the pin connecting the pawl plates to the connecting rod. Meanwhile the producer is kept in operation with the other feed.

There is a small poke hole in the lower part of valve seat casting through which tar and crusts which sometimes form on the sides of the discharge openings may be loosened with a bar. This hole is closed with a tapered plug which is easily removed.

A counterweight deflector plate is hung above the feed valve. This guides the coal into the valve pockets and prevents the pockets from becoming overloaded. As the valve turns, there is provision made for reserve displacement which allows the coal to fall back into the valve pocket. Thus any protruding lump passes the shear point without obstruction unless it is excessively large.

A water drip lubricator moistens the valve seat and keeps the tar plastic and the valve seat lubricated.

The feed is driven from an eccentric common with the poker. The connecting rod to the feed is equipped with a shear pin release to protect the machine from possible damage in event of foreign matter becoming caught in the mechanism.

The movable parts of each feed are driven from a common rocker shaft. The speed of the upper measuring wheel is regulated by means of a traveling nut and hand wheel which regulates the throw of the driving pawls. With this arrangement the amount of coal feed is under absolute control.

The entire construction is extremely rigid and simple—ensuring a long life to the mechanism, a minimum of attention and repair.

Disposal of Ash

The ash is deposited in water and drawn to the outer edge of the ash-pan by a scraper. At any desired time, the ash is removed from the pan automatically by an ash-plow. Both the scraper and the ash plow are put into operation by means of adjusting screws at certain periods by the operator, depending on the condition of the ash, fire and fuel bed which also determines the quantity of ash to be removed.

The Blower

In the Wellman producer, the proper amounts of air and steam are introduced by the Wellman blower. The blower with blast inlet pipe and cast iron deflecting plate is at the base of the producer.

The blower is to a producer what the throttle is to a locomotive. The amount of steam used controls the amount of air admitted and hence controls the quality and quantity of the gas.

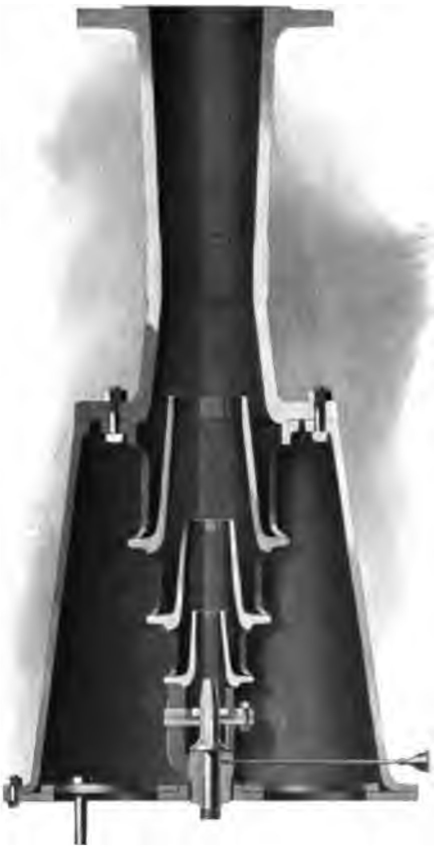


Figure 98—Cross Section of Air Blast Blower

The steam entering at the base of the blower passes up through three conical shaped ports, each a little larger than the preceding one. At each port air is drawn in, which mixes with the steam. This blower distributes the blast to the sides of the fuel mass as well as to the middle, thus adding materially in the regulation of combustion and the gas-making process.

Advantages

It will be seen from the design that the Wellman producer possesses certain distinct advantages including:

Less labor required:

Under ordinary conditions, one gas man will operate six producers equipped with mechanical feeders. Two additional laborers for cleaning fires and attending to the coal and ash is all the labor required for a plant of that size. The producer requires no hand poking except when breaking down fires.

Better distribution of coal:

Due to location of feed hoppers, rotation of body of producer, and action of mechanical poker.

Better distribution of ashes:

Due to rotation of ash receptable. Poker also assists in working the ashes down uniformly.

Better quality and more uniform supply of gas:

Due to the continuous and uniform mechanical treatment of the material..

More gas produced per square foot of producer area:

Due to the beneficial and uniform action of the mechanical poker in distributing and agitating the mass of coal.

This means

Less number of units required for equal gas capacity; less cost of foundations; fewer flues and valves; fewer nozzles; less boiler horsepower required for blowing purposes; less space occupied and smaller buildings; therefore, less initial investment for producer plant, and very much less yearly expense for maintenance and operation.

Power for driving—From 2 hp. to 3 hp. is required to operate the producer but it is equipped regularly with a motor of 5 hp. at 1150 rpm.

Cooling water—Approximately twenty gallons of water per minute is required.

Steam consumption—The producer operates continuously on an amount of steam as low as 0.166 pounds of steam per pound of fuel gasified.

Shutting off—Under ordinary conditions by completely shutting-off steam and air, a Wellman producer can be banked for 48 hours and will be ready to make gas within 30 minutes after the introduction of steam and air.

Particular care has been given to the selection of materials for each part of the Wellman machine. Parts which are subjected to shock or strain are open-hearth steel castings.

Brick lining—The bricks used for lining this producer are standard No. 1 and No. 2 key, second quality, fire-brick. No special shapes being used, brick for relining can be obtained more quickly and at lower cost than would be the case if special shapes were required.

Replacing poker tip—The removable tip of the poker being of carefully selected material should stand about a year of constant use under ordinary conditions. By having a spare poker and trunnion on hand, a complete change can be made in about twenty minutes without shutting off the gas.

Operation and Capacity

Fuels—The Wellman producer works successfully on anthracite and bituminous coal as well as on crushed coke and coke breeze. The most desirable coals for use in the producer are those running from 30% to 40% volatile and from 52% to 65% fixed carbon with ash content under 15%. When mechanical feeder is used, the coal should be crushed so as to pass through a 4-inch ring and may contain as much as 35% of fines.

Table No. 63

Typical Analysis of Coal Gasified

Approximate Analysis		Ultimate Analysis of Volatile	
Volatile Matter	34.94%	Carbon	17.93%
Fixed Carbon	58.30%	Hydrogen	5.02%
Total Carbon	76.23%	Nitrogen	1.38%
Ash	5.65%	Oxygen	10.61%
Moisture	1.11%		
			34.94%

Capacity

The Wellman producer using mechanical feeder will gasify 3,000 pounds of ordinary bituminous gas coal per hour under normal working conditions, forming a gas containing an average of 148 Btu. per cubic foot and with a loss in the ash of less than 1% of the combustible charged. One pound of coal will produce 60 to 70 cu. ft. of gas at 62° F.

Analysis of Gas

To form a correct opinion of the value of a gas producer it is necessary to know the potential heat of the gas which it makes. To do so certain standards of values must be adopted. These are the calorific values of the constituents of the gas, such as hydrogen, carbon, and their compounds. The weight of gas per cubic foot varies according to its temperature and the pressure to which it is exposed. Consequently the amount of the combustible in a cubic foot of gas, and the value of the gas itself as a fuel is proportional to its temperature and pressure. In scientific work the standard conditions assumed are 32° Fahrenheit for temperature and 29.0″ for mercurial barometric pressure, ordinarily considered to be 30.0″ for convenience sake, which is the barometric pressure at sea level.

Engineering investigations have to do with problems under ordinary working conditions rather than under the theoretical assumed conditions of a scientist's study or artificial conditions which he can obtain in his laboratory. This leads to an abandonment in practical engineering of the temperature of 32° and the adoption of 62° Fahr. which more nearly approaches the average working temperature of mills and work shops. This departure from 32° in favor of 62° is generally approved of and used. Owing to the fact that a gas is denser at 32° than at 62° one cubic foot of gas will weigh proportionally less or only 94.25% at 62° than at 32°. So that if a gas is reported as yielding 185 Btu. per cubic foot at 32° it gives but 174.4 Btu. at a temperature corresponding to ordinary average temperatures formed in a workshop. Thus one is given the impression (as the average man is accustomed to think of usually experienced temperatures) that the gas is over 6% richer than it is.

The calorific values of elementary substance composing fuel gases have been experimentally determined by a large number of scientists over a considerable range of time. Due to the refinement of processes and instruments the older values such as 62,032 Btu. per pound of hydrogen have been abandoned in favor of the more recent and accurate values, in most of the present day discussions.

When hydrogen or any hydro-carbon is oxidized, water is formed. At the temperature of combination the water is a pure gas. The heat generated and available for use amounts to 51,892 Btu. per pound of hydrogen burned. When this gaseous water is cooled to 32° F. and condensed to a liquid, there is a further release of 8,734 Btu. which can be used making the total heat of combustion 60,626 Btu. These two quantities 60,626 and 51,892 are named the "high" and the "low" heat of combustion respectively. From all furnaces or generators in which hydrogen combustion occurs, the resultant water passes out at a high temperature as a gas or vapor, and are not cooled to 32° and condensed to water until they have been exhausted out of the stack in the atmosphere and the 8,734 Btu. of condensation are lost.

These considerations apply equally to producer gas and gas producers as to any other furnaces. It follows as a consequence that the relative merits of hydro-carbon gases and gas producers must be figured from a practical engineering standard such as 62° Fahr. which is more nearly approximately normal average work shop temperature, and from 30" barometric pressure, and not from a hypothetical condition which is not found in operating experience.

As an indication of what may be obtained in ordinary producer operation (not specially prepared testing conditions) and using ordinary gas coal, the following volumetric gas analyses are given:

Table No. 64

Gas Analyses

	%	%	%	%	%
CO_2	5.90	4.48	6.50	8.90	4.8
CO	22.63	26.32	22.36	19.90	24.1
CH_4	2.70	3.86	3.75	3.77	2.1
C_2H_4	.42	.40	.30	.32	1.1
H_2	12.58	10.60	12.77	12.73	14.4
O_2	.02	.018	.00	.00	0.4
N_2	55 75	54.322	54.32	54.38	53.1
Total	100.00	100.00	100.00	100.00	100.00

Btu. cubic foot at 30" pressure:

HEAT OF COMBUSTION—Btu.

62° Low	137.9	154.3	146.0	137.6	150.2
32° High	154.5	173.0	165.3	156.3	171.1
Per pound	2062.	2305.	2184.	2057.	2245.0

Ave. weight per cu. ft. at 62° and 30" = 0.067 lbs.
Cu. ft. per pound 62° and 30" = 14.95 cu. ft.

It is the ultimate analysis which should be considered if an intelligent estimate is to be made of the final quantity and quality of the gas generated.

Steam and air are essential to the making of uniform gas. The steam used in the Wellman producer runs as low as 0.166 lbs. per pound of fuel gasified. The amount of air blown by means of this steam averages 3.9 lbs. per pound of fuel.

Table No. 65

A Typical Analysis of Producer Ash

Combustible	15.13%
SiO_2	24.10%
CaO	12.10%
Al_2O_3	18.52%
S	17.40%
Fe_2O_3	12.75%
	100.00%

The method of determining the ash loss is not a complicated problem, but for sake of clarity it is explained below.

From the analysis of the coal, take all elements not combustible.

Thus

Vol. C	34.94%		
F. C.	58.30%		
Ash	5.65%	Ash	5.65%
Moisture	1.11%	Moisture	1.11%
	100.00%	minus	6.76 = 93.24% of pure coal.

The ash analysis from the producer shows 15.13% combustible as 100–15.13 = 84.87% true ash.

Now the per cent of refuse of the original charge would be

$$\frac{\text{Ash in the coal} = 5.65\%}{\text{True ash produced} = 84.87\%} = 6.65\%$$

of ash produced from the original charge by the operation of the producer. Now 5.65% of this amount is the ash of coal so 6.65—5.65 = 1% of the original charge lost through producer operation or $\frac{100\%}{93.24\%}$ = 1.07% of combustible lost in the ash.

Efficiency of Wellman Gas Producer

During the usual routine of open hearth furnace operation in a large steel mill, a record was kept for a week of the quantities of materials and other features which are used in the following pages to show the performance of the four gas producers supplying two 60-ton basic stationary open hearth furnaces.

Open Hearth Data

Number and capacity of furnaces	2 of 60-ton heats
Hearth	32′-0″ x 14′-9″ ratio 2:2
Hearth area, and per ton of steel	472 sq. ft.; 8.87 sq. ft.
Time under observation	1 week of 161 hrs. 32 min.
Number and actual size of heats	23, of 70.0 tons of steel
Steel produced	1615.0 tons of steel
Steel produced per heat per sq. ft. hearth	0.148 tons of steel
Hearth area per ton of steel	6.72 sq. ft.

Furnace in full operation per heat	63%	4 hrs.	24 min.
Furnace in ¾ operation per heat	17%	1 hr.	14 min.
Furnace in ½ operation per heat	14%	1 hr.	0 min.
Furnace in ¼ operation per heat	1%	0 hrs.	3 min.
Furnace in off operation per heat	5%	0 hrs.	20 min.
Total	100%	7 hrs.	1 min.
Furnace time per heat			
Charging time, gas on ¾ working	18%	1 hr.	14 min.
Working time, gas on full	62%	4 hrs.	18 min.
Hot Metal Charging, gas on ¼	1%		3 min.
Tapping, gas on full	1.4%		6 min.
Patching, gas off	3.6%		20 min.
Waiting on material, gas on ½	14%	1 hr.	0 min.
Total	100%	7 hrs.	1 min.

Gas Producer Data

Number	4 Hughes (Wellman)
Type	Mechanical poker, hand fired.
Diameter inside brick lining	10′-0″
Cross section area	78.54 sq. ft.
Coal charged	856,000 lbs.
Coal charged (2240 lbs. per ton)	382.14 tons
Average time producer off (during cleaning) per day	32 min.
Coal gasified per producer per hour	1325 lbs.
Coal gasified per sq. ft. producer area per hour	16.9 lbs.
Steam blower nozzle 7/16″ dia.	0.15 sq. in.
Pressure	45 lbs. per sq. in.
Steam blown during test	242,256 lbs.

Coal Analysis

Volatile matter		
Carbon	17.93%	
Hydrogen	5.02%	
Nitrogen	1.38%	
Oxygen	10.61%	
Total	34.94%	
Fixed Carbon		58.30%
Total Carbon		76.23%
Ash		5.65%
Moisture		1.11%
Pure Coal 100%—(5.65%+1.11%) =		93.24%

Ash Analysis

True Ash (incombustible)	84.87%
Combustible	15.13%
Total	100.00%
Refuse (ashes)	
5.65% ash in coal ÷ 84.87%	6.65%
Coal lost in ashes	1.07%
6.65%—5.65% = 1.00% combustible	
1.00% ÷ 93.24% = 1.07% coal in ashes	
Incombustibles	

Fe	0.85%	CaO	0.80%
S	1.16%	Al_2O_3	1.30%
SiO_2	1.54%		
		Total	5.65%

Producer Gas Thermochemistry

Low Values at 62° F.,—30" Barometric Pressure

Symbol	Vol. 1 cu. ft. %	Wt. in 1 cu. ft. Gas Made at 62° F., Lb.	Wt. %	Heat of Combination 1 cu. ft.	Wt. in 1 cu. ft. of Producer Gas			
					Oxygen	Carbon	Hydrogen	Nitrogen
CO	22.63	0.01665	25.00	72.19	0.00952	0.00713		
CH_4	2.70	0.00114	1.70	24.44		.00085	0.00029	
C_2H_4	.42	0.00032	.48	6.31		.00027	.00005	
H_2	12.58	0.00067	1.00	34.59			.00067	
O_2	.02	0.00002	.02		.00002			
N_2	55.75	0.04114	61.50					0.04114
CO_2	5.90	0.00689	10.30		.00500	.00189		
Total	100.00	0.06683	100.00	137.53	0.01454	0.01014	0.00101	0.04114
		at 32° F.		146.00				

Cu. Ft. of gas per pound = 1.0 ÷ 0.06683 = 14.964 cu. ft.
Heat of combustion per pound of gas 137.53 ÷ 0.06683 = 2050.0 Btu.

Steam Consumption

Average gauge pressure of steam at blower 45 lbs. = 60 lbs. absolute	
Steam per minute per producer Area × abs. press. × 60 sec. ÷ 70 =	7.713 lbs.
Total steam used in 161 hr. 32 min. as calculated	299,018 lbs.
Deduct for reduced blowing	56,762 lbs.
Net actual steam used	242,256 lbs.
Steam per ton of coal gasified	634 lbs.
Steam per producer per hour	375 lbs.
Steam per producer per hour	12.5 H. P.

Air Analysis

	Moist as used	Dry
Nitrogen	75.92%	77.0%
Oxygen	22.67%	23.0%
Water Vapor	1.41%	
Total	100.00%	100.0%

Coal Gasified and Product

Line	Item	% Weights	Weights Lbs.	Weights per ton of Coal Lbs.	Weights per ton of Steel Lbs.
1	Coal lost in ashes	1.07	9,160	23.9	5.65
2	Coal lost in soot	.69	5,906	15.4	3.64
3	Coal lost total	1.76	15,066	39.3	9.29
4	Coal gasified	98.24	840,934	2200.7	520.00
5	Coal total	100.00	856,000	2240.0	529.29
6	Carbon in coal gasified	76.23	641,000	1677.5	396.00
7	Gas volume cu. ft.		63,215,000	165,620.0	39142.00
8	Gas weight lbs.		4,224,660	11,055.0	2616.00
9	Gas volume cu. ft. per pound of coal gasified				73.9 cu. ft.
10	Gas weight lbs. per pound of coal gasified				4.93 lbs.
11	Steam used lbs.		242,256	634	150.3
12	Air used lbs.		3,419,200	8960	
13	Heat of combustion in Gas Btu.		8,692,960,000	22,800,000	5,385,000

Notes

6 840,934×76.23%

7 Gasified Coal Carbon ÷ Wt. of carbon per cu. ft.
641,000 ÷ 0.01014

8 Vol. of gas × Wt. per cu. ft.
63,215.000×0.06683 lb.

9 (7) ÷ (15)

10 (8) ÷ (5)

11 See paragraph of "Steam Consumption."

12 Wt. of Gas×(61.5% = Nitrogen by weight in producer gas)
4,224,660×61.5% = 2.595,835 lbs. nitrogen in the gas. This nitrogen is supplied by the air as blown in of which the nitrogen runs 75.92%
2,595,835 ÷ 75.92% = 3,419,200 lbs. of moist air.

13 Vol. at 62° (7)×147.57 Btu.

Sensible Heat in Coal to Producer

Symbol	In Coal by Weight %		Sp. Heat of One Lb. of Coal
C	76.23	0.1567+(8×0.00036) =0.15958	0.12165
H	5.02	3.370 +(8×0.00017) =3.37136	0.16924
N	1.38	0.2405+(8×0.0000119)=0.24060	0.00332
O	10.61	0.2104+(8×0.000010) =0.21048	0.02233
Ash	5.65	0.1800+(8×0.) =0.1800	0.01017
			0.32671
		Call this	0.327 Btu.

Heat to Producers per Ton of Coal Charged

	Per Ton Coal Lbs.	Btu. per Lb.	Heat of Combustion	Observed Temperature	Range of Temperature	Sp. Heat per degree	Sensible Heat Btu.
Coal	2,240	12,917	28,934,100	70	8	.327	5,860
Steam	634	1,171	740,800				
Air (dry)	8,834			90	28	.234	57,880
H_2O in Air	126	1,109	139,740	90(Sat. Pt.)	28	.426	1,500
H_2O in Coal	25			70(Sat. Pt.)	8	1.00	200
Total			29,814,640				65,440
Total of Heat of Combustion and Sensible Heat							29,880,080

Total as above per cu. ft. 180.4 Btu. Total as above per lb. of gas 2701.0.

Sensible heat—Coal 2240×8×327=5860
Air 8834×28×.234=57880
Etc.

Sensible Heat in Gas

Specific heat for range of temperature from 62° to 1400°=1332°F.

	Gases	% by Weight		For 1° F. and 1 Lb. Specific Heat Btu.
1	CO	25.00	0.2405+[(1332°×0.0000119)=0.0159]=0.2564	0.06410
2	CH_4	1.70	.5300+[(1332°×0.000150) = .1898]=0.7198	0.01236
3	C_2H_4	.48	.3670+[(1332°× .000130) = .1732]=0.5402	0.002593
4	H_2	1.00	3.3700+[(1332°× .000170) = .2264]=3.5964	0.035964
5	O_2	.02	.2104+[(1332°× .000014) = .01865]=0.2290	0.000046
6	N_2	61.50	.2405+[(1332°× .0000119)= .01585]=0.2564	0.157686
7	CO_2	10.30	.1900+[(1332°× .00006) = .07992]=0.2699	0.02780
8		100.00	Specific heat of producer gas	0.300425

Heat Delivered in Producer Gas per Ton of Coal Charged

	Weight Lbs.	Btu. per Lb.	Heat of Combustion	Rise in Temp. °F.	Spare Heat per °F.	Sensible Heat Btu.
Gas	11,055	2050	22,663,000	1338	0.300	4,525,000
Water	216	1109	240,000	1311	0.561	160,000
Total			22,903,000			4,685,000
Total						27,588,000
Heat per cu. ft. of gas						166.4
Heat per lb. of gas						2495.5

Sensible heat—Gas 1338°×0.300×11055 lbs.
Water 1311°×0.561×216.
Initial gas temperature 62°. Final 1400°. Rise 1338°.
Saturation point of air (observed) 89°. Rise 1311°.

Moisture

Water in	%	Total Weight	Weight per ton of	
			Coal	Steel
Coal	1.11	9,500 lbs.	24.85	5.89 lbs.
Air	1.41	48,210 lbs.	123.40	29.70 lbs.
Steam	100.00	242,256 lbs.	634.00	150.00 lbs.
Total		299,966 lbs.	782.25	185.59 lbs.

Notes
Coal 856,000×1.11%
Air 3,419,200×1.41%

Analysis—by Weights—per Ton of Coal Charged

		Lbs. Wt. per Ton Coal	Carbon Lbs.	Oxygen Lbs.	Hydrogen Lbs.	Nitrogen Lbs.
1	Coal	2,240	1677.5	238	112	31
2	Air	8,940	None	2,141	None	6,799
3	Steam	634	None	555	79	None
4	Gas	11,053	1677.5	2,408	167	6,813

Notes

(1) 2,240 lbs.×76.23%;×10.61%

(2) 8,940 lbs.×77.0%

(3) 634 lbs.×16/18;×2/18

(4) 11,053 lbs. Equivalent of 165,620 cu. ft.; 165,620 cu. ft.× 0.01454 lb. oxygen.

165,620 cu. ft.×0.01014 lb. carbon, etc. See table of "Producer Gas Thermochemistry."

Hydrogen in Coal (from above) 112+79=191 lbs.

Hydrogen in gas (from above) as hydrogen=167 lbs.

Hydrogen in Gas (from above) as water vapor=24 lbs.

In burning hydrogen, the resulting H_2O is 9 times the weight of the hydrogen.

Corresponding weight of water=24×9= 216 lbs.

Corresponding weight of water (7000 grains per lb.)= 1,512,000 grains.

Water vapor per cubic foot of gas 1,512,000÷165,620 cu. ft. =9.13 grains

Thermochemical Efficiency

$$E=\frac{\text{Thermochemical energy delivered}}{\text{Potential energy suppplied}}$$

$$=\frac{\text{Heat in Producer Gas}}{\text{Heat to Producers}}=\frac{27588000}{29880000}=92.33\%$$

For Hot Gas

$$E=\frac{27588000}{29880000}=92.33\%$$

For Cold Clean Gas

$$E=\frac{27588000-4{,}685{,}000}{29{,}880{,}000}=\frac{22{,}903{,}000}{29{,}880{,}000}=77.00\%$$

Hot and Cold Gas

In the case under discussion the calorific value of the gas fixed by its chemical composition at 62° using the low values of the hydrogen heats of combustion is 137.53 Btu. per cu. ft. or 2050 Btu. per pound. The heat actually delivered at a temperature of 1400° is the sum of the heat of combustion at 62° and the sensible heat of the gas at 1400° and is 166.4 Btu. per cu. ft. or 2496 Btu. per pound. The sensible heat of 446 Btu. per pound is lost to the consumer when the gas is cleaned and delivered at 62°. This loss amounts to 17.9% of the heat of the gas delivered to the cleaner.

Summary

Per Ton of Coal Charged

Coal charged	1 ton	2240 lbs.
Ash lost		126.5 lbs.
Coal lost in ash, 23.9 lbs.; in soot, 15.4 lbs.		39.3 lbs.
Coal moisture		24.8 lbs.
Coal gasified		2200.7 lbs.
Calorific value of coal per pound		12917.0 Btu.
Steam used in blower		634.0 lbs.
Air blown		8960.0 lbs.
Gas made		165620.0 cu. ft.
Gas made per pound of coal		73.93 cu. ft.
Gas made per pound of coal		4.94 lbs.
Gas cubic feet per pound 62° F.		14.96 cu. ft.
Gas weight per cu. ft.		0.06683 lbs.
Gas Temperature		1400.0° Fahr.
Producer Efficiency Hot Gas		92.33%
Producer Efficiency Cold Gas		77.00%

Gas Production Data

One pound of carbon as it occurs with other elements in the form of coal makes from 80 to 90 cu. ft. of producer gas.

If one pound of carbon is burned completely to CO_2, 14544 Btu. are released, but only 4325 Btu.'s are released if the carbon is burned to CO. Therefore, with each pound of carbon carried from the producer in the form of CO gas, we have appearing a latent thermal value, which will be released on combustion 14544–4325 = 10219 Btu. These heat units must be divided between the 80 or 90 cu. ft. of gas generated, giving a heat value of 113 to 129 Btu. per cu. ft.

The actual gas is enriched by a small volume of distilled gas from the first zone which will be a rich coal gas. This gas is always of a small volume but it may contain a heating value of 300 to 400 Btu. per cu. ft.

The greater the proportion of this kind of gas, the larger will be the unit heating value in the final product. This distilling process is the first operation in the producer and, for a given fuel, the quantity and quality will remain practically constant.

By decreasing the amount of carbon carried out of the producer in the form of diluent or weak gas, which can be easily done by cleaning the fires so often that the carbon in the ash becomes excessive, the heating value per unit volume can be considerably raised directly as the producer efficiency is lowered.

It is, of course, desirable to obtain as rich a gas as possible but 95% of the result, when an unusually rich gas is obtained, can be charged directly to the kind of fuel, and in any case a high Btu. value is no indication of producer efficiency.

The ultimate test of a machine is the degree of its ability under adverse operating conditions and using low grade raw material to produce reasonably satisfactory results. Under conditions closely approximating to perfection in operatives and raw materials, experience shows that inferior machines tend to approach towards the efficiency of the better machines.

The following results were obtained recently by the management of a plant using both the Wellman and a competing producer. The report stated that conditions of operation were severe, and coal used was of exceedingly poor quality and the producers were working under the same conditions.

Table No. 66

Producer Gas Analysis

Gas Analysis	Wellman Mechanical Producer	"XYZ" Producer
CO	19.4%	11.4%
CH_4	4.3	2.4
C_2H_4	0.3	0.0
H_2	11.0	7.6
CO_2	8.5	13.7
N_2	56.5	64.9
Btu. per cu. ft.	146.2	105.7
Btu. per cu. ft. 32° Low	155.0	112.0

Coke Producer Gas

From another plant using Wellman Producers operating with nut size coke, we received the following report of ordinary operation:

Table No. 67

Coke Analysis

Moisture	3.17%
Vol. matter	2.76%
Fixed carbon	82.07%
Ash	12.0 %
Total	100.00%

The gas analysis showed the following:

	Range	Ave.
CO	19.5% to 25.8%	23.80%
CH_4	1.4% to 4.0%	2.40%
H_2	9.3% to 18.0%	12.50%
O_2	.1% to 2.2%	0.4 %
CO_2	4.0% to 7.3%	6.2 %
N	53.2%	54.7 %
Btu.	130.0 to 158.0	143.00

Table No. 68

Record of Wellman Mechanical Gas Producer Operation—Bituminous Coal

AT —————— O. H. PLANT ——————1919

OBSERVATIONS

Producers for O. H. Furnaces.		Plant A	Plant B
Conditions............		Ordinary Operation of Plants	
Date..................		1919	1919
Steam Pressure.........	Lbs.	23.4	59.3
Gas Temperature.......	F.°	1209	1293
Length of Furnace and Producer Run........		One Week 139 Hours 13 Min.	One Week 128 Hours 25 Min.
Open hearth steel made..	Tons	806	722
Steam used in Producers	Lbs.	303,700	362,800
Coal used in Producers..	Lbs.	818,200	744,800
Combustible in coal used in Producers.........	Lbs.	626,700	566,600
Coal per Producer hour..	Lbs.	1,959	2,900
Combustible per Producer hour...........	Lbs.	1,500	2,206
Soot..................	Lbs.	7,900	10,800
Ashes.................	Lbs.	66,200	63,400
Steam used per pound of coal.................	Lbs.	.371	.487

RESULTS

Producers for O. H. Furnaces.		Plant A	Plant B
Conditions............		Ordinary Operation of Plants	
Gas per pound of coal...	Cu. Ft.	68.4	68.4
Gas per pound of combustible............		89.3	89.9
Heat per pound of coal..	Btu.	13,700	13,700
Heat per pound of combustible............	"	17,890	18,010
Heat per pound coal to O. H. Furnace.....	"	12,800	12,600
Heat per pound combustible to O. H. Furnace...............	"	16,720	16,500
Efficiency of Producer...	%	93.5	92.0
Combustible in Ash.....		1.47	1.84

AVERAGE OF GAS ANALYSIS FOR THE WEEK

	CO_2	C_2H_4	O	CO	CH_4	H_2	N_2	Btu.
Plant A..	6.5	.30	.0	22.36	3.75	12.77	54.3	146.0
Plant B..	8.6	.32	.0	19.9	3.77	12.73	54.68	138.0

Table No. 69

Wellman Mechanical Gas Producer Gas Analyses

COAL—BITUMINOUS OF PITTSBURGH DISTRICT

Made by —————————— Steel Co. and reported to Wellman-Seaver-Morgan Co.

PERCENTAGE BY VOLUMES

Producer No..........	1			2			3		4	5	6					7			Ave.
Test No.............	5	8	11	6	9	12	7	10	16	3	1	4	13	14	17	2	15	18	%
Carbon Dioxide........	4.0	4.8	5.0	4.0	5.5	4.0	3.8	4.6	3.6	3.4	3.2	3.2	5.6	3.8	3.6	4.0	3.8	3.4	4.07
Illuminants...........	.8	.6	.8	.8	.5	.8	.8	.5	.6	.6	.8	.68	.6	.8	.8	.6	1.0	.8	.72
Oxygen......	.2	.2	.2	.2	.0	.2	.2	.1	.2	.2	.2	.2	.2	.2	.4	.2	.6	.4	.22
Carbon Monoxide......	25.0	26 0	23.8	25.8	26.0	25 4	26.0	26.1	25.2	28.0	26.0	27.6	23.6	25.8	27.0	26.2	25.8	26.8	25.90
Methane.............	3.0	2.8	3.16	3.1	2.8	3.88	3.16	3.0	3.16	2.7	2.86	2.8	2.64	3.25	2.39	2.5	3.39	3.59	2.95
Hydrogen	11.0	11 1	11.71	10.8	11.2	10.8	10.9	11.0	9.83	9.61	10.5	10.0	10.39	8.83	10.23	10.27	10.69	11.76	10.59
Nitrogen.............	56.0	54.5	55.23	55.3	54.0	54.92	55.14	54.7	57.41	55.49	56.44	55.6	56.97	57.32	55.58	56.03	54.72	53.25	55.55
Btu. per cu. ft. at 62° F.	154.	149.	149.	152.	148.	158.	154.	143.	145.	149.	150.	151.	152.	148.	148.	144.	158.	163.	149.
Btu. per cu. ft. at 32° F.	163.	158.	158.	161.	157.	167.	163.	152.	154.	158.	159.	160.	161.	157.	157.	153.	167.	173.	158.
Combustible in the Ash.	11.0				10.9						9.76					9.76			
Sulphur.............					1.06						.98					.98			

The Heat of Combustion (in Btu.'s) is based on the "Low" value of Hydrogen—51892 Btu. per pound.

Using the "High" values for Hydrogen and the Hydrocarbons as is often (though erroneously) done the average value would be 159.2 Btu. per cu. foot instead of 149.0 as above, using the temperature of 62° F.

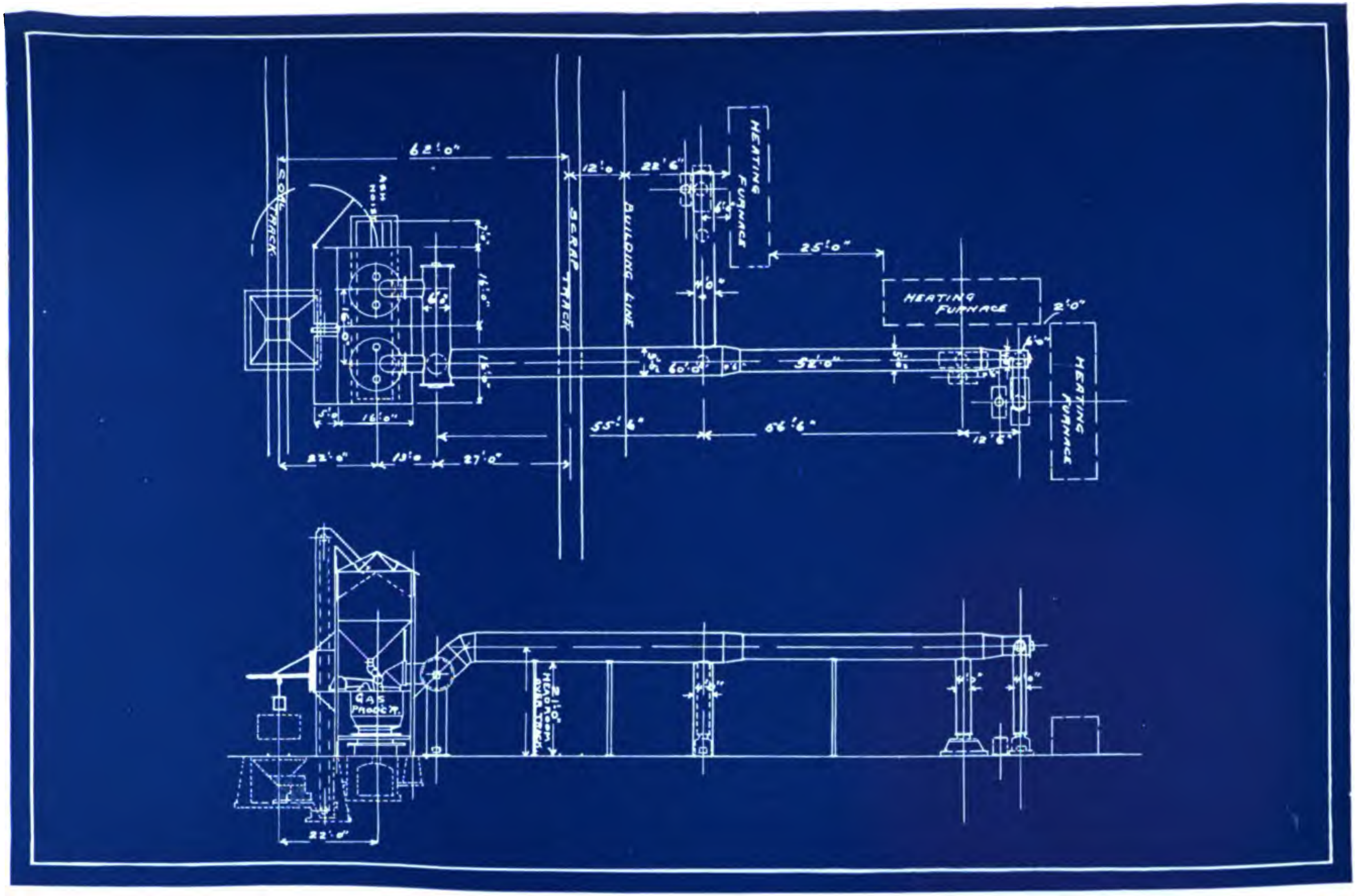


Figure 99—LAYOUT FOR TWO WELLMAN MECHANICAL GAS PRODUCERS

For heating billet furnaces.

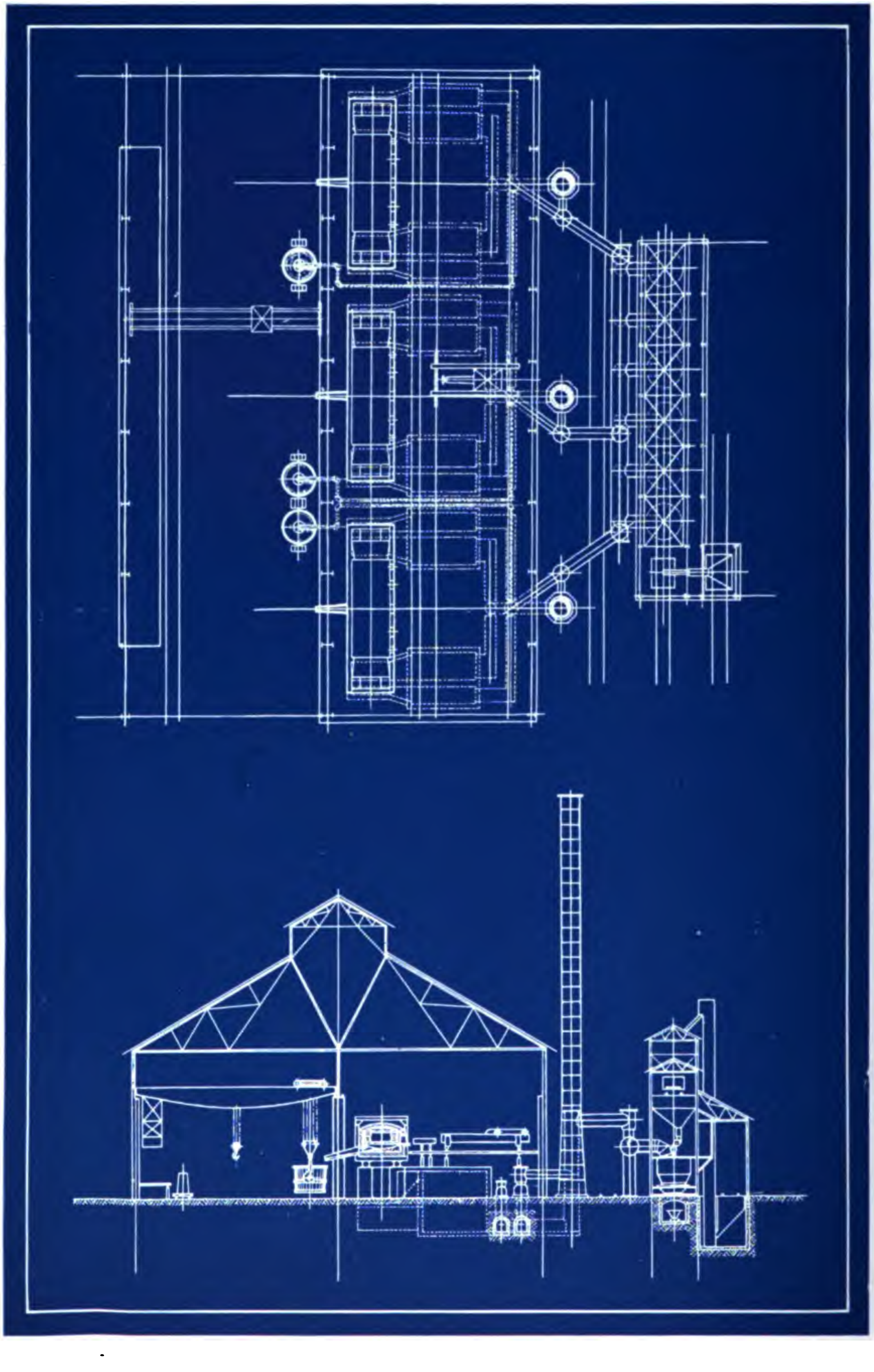


Figure 100—LAYOUT OF SIX PRODUCERS
For an Open Hearth Plant of three 50-ton steel furnaces.

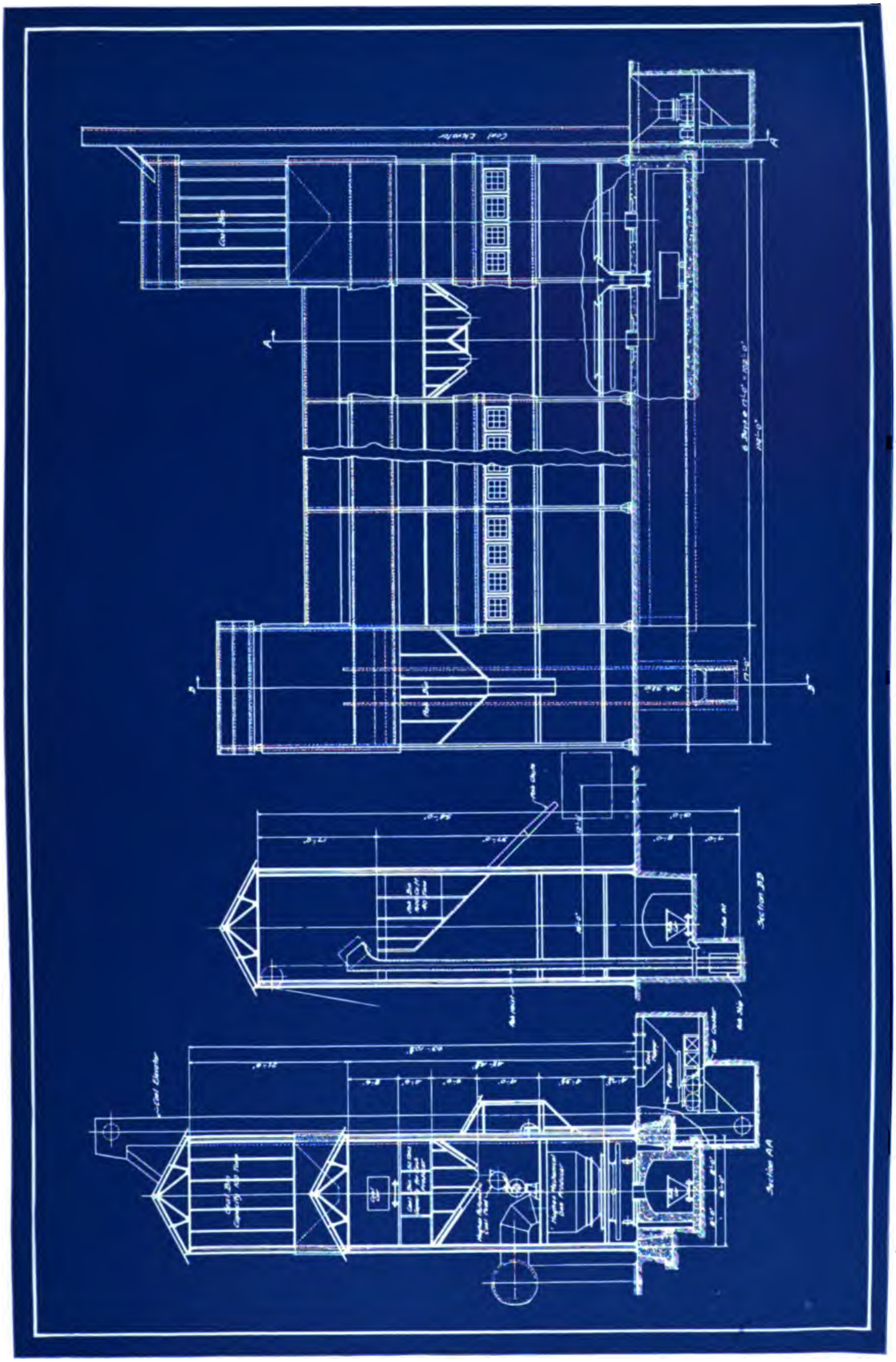


Figure 101—LAYOUT FOR SIX WELLMAN (HUGHES) MECHANICAL GAS PRODUCERS

Complete layout includes coal crusher, hoist, bins holding 40 tons per producer, and general bin of 100 tons coal ash bin, conveyor, and loading chute.

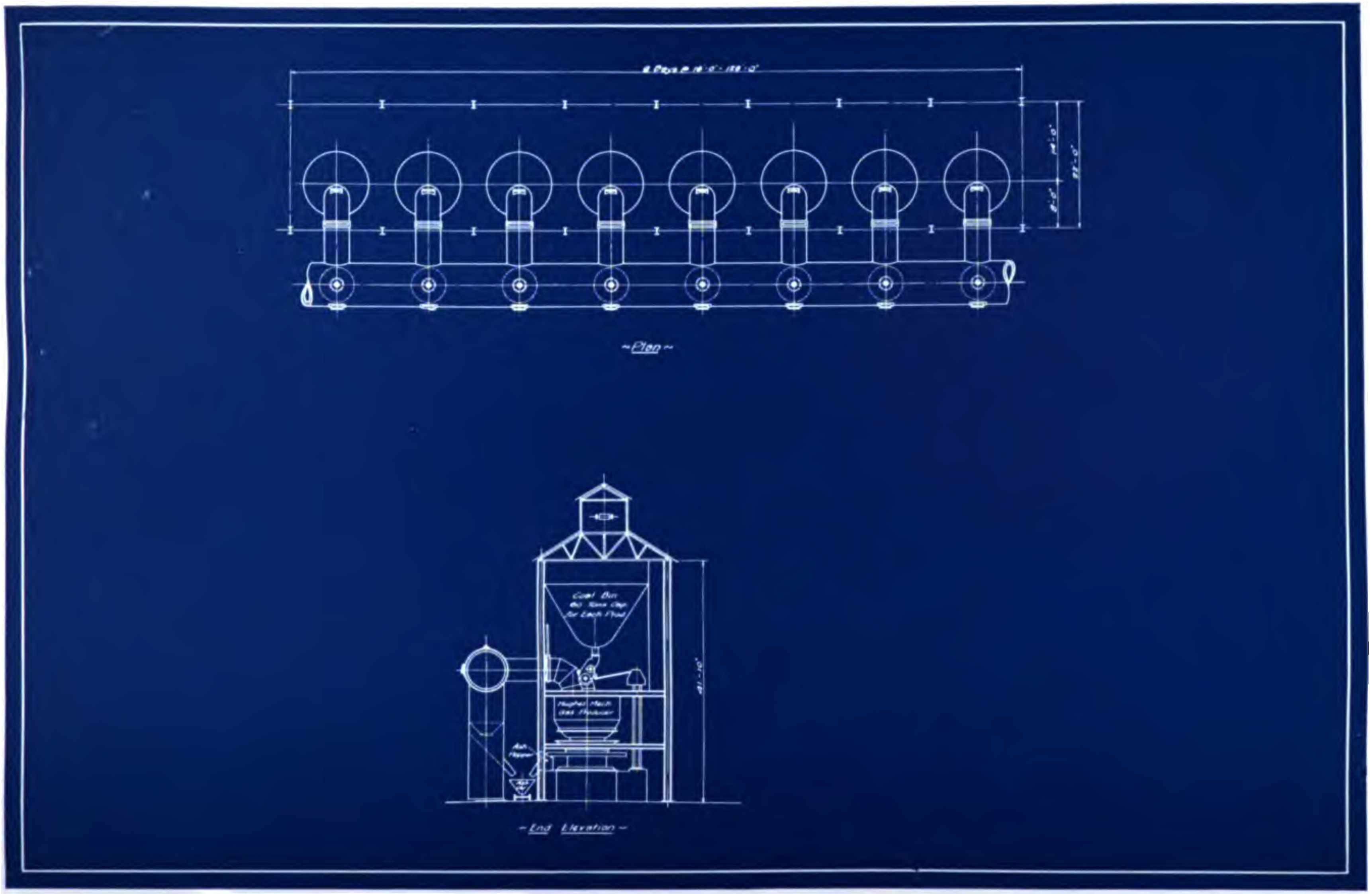


Figure 102—LAYOUT FOR EIGHT WELLMAN (HUGHES) MECHANICAL GAS PRODUCERS

The simplicity of such a plant commends itself to engineers and operating executives.

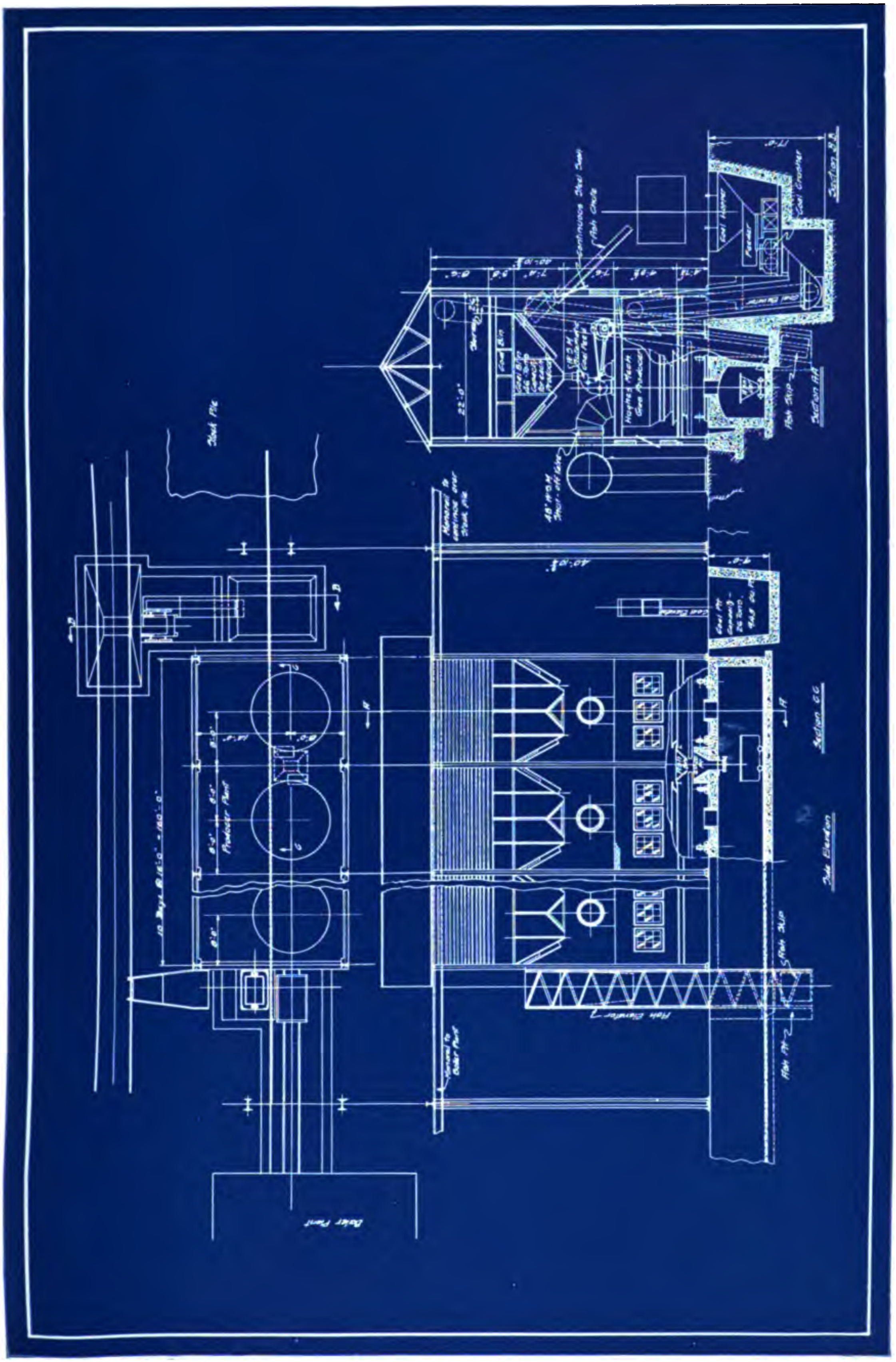


Figure 103—LAYOUT FOR TEN WELLMAN (HUGHES) MECHANICAL GAS PRODUCERS

All operations of gasification are mechanical.

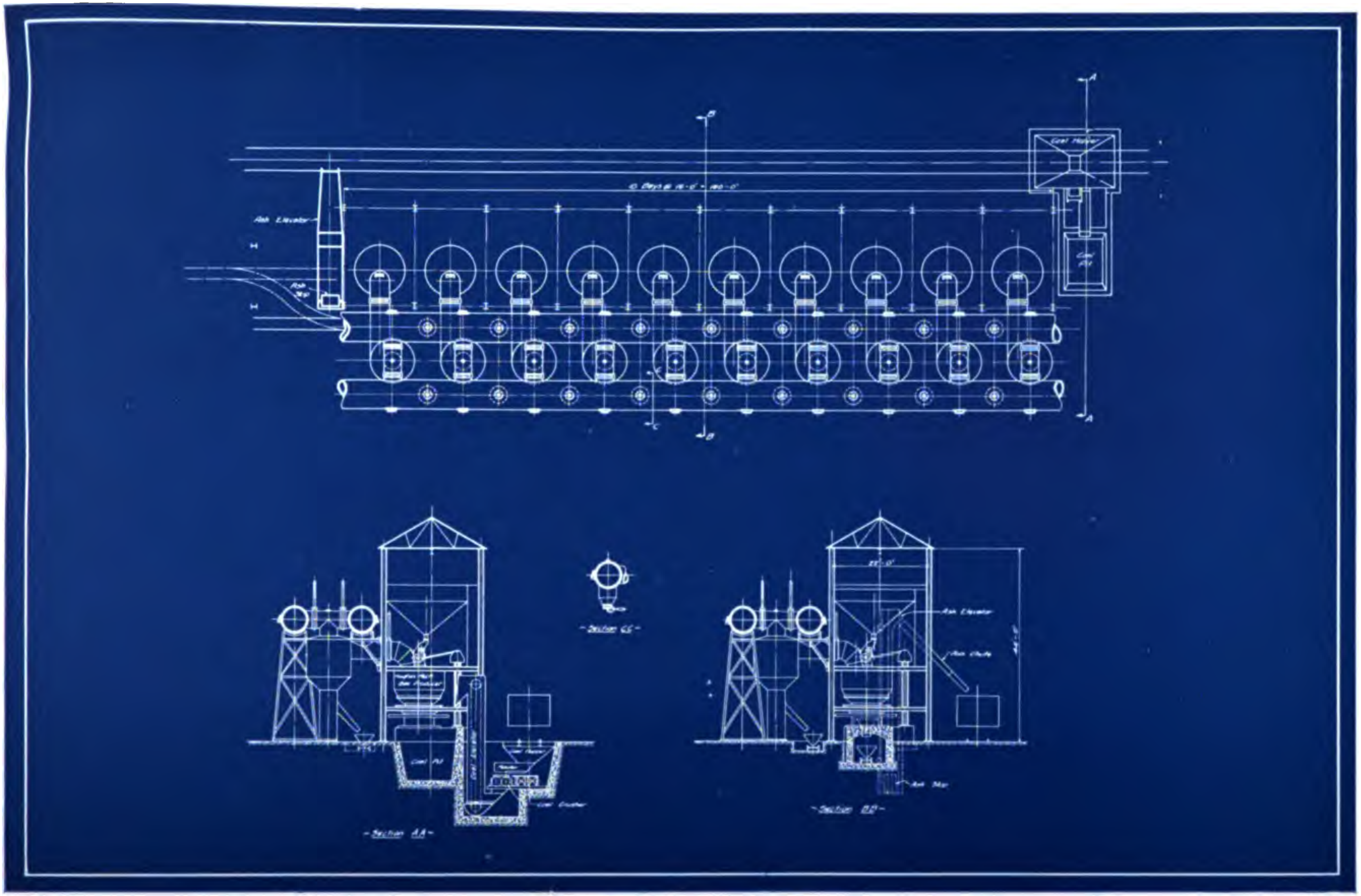


Figure 104—LAYOUT OF A 10 GAS PRODUCER INSTALLATION

The Wellman (Hughes) mechanical gas producers with coal and ash handling equipment make a plant almost automatic, and supplya large quantity of rich gas at a small expense.

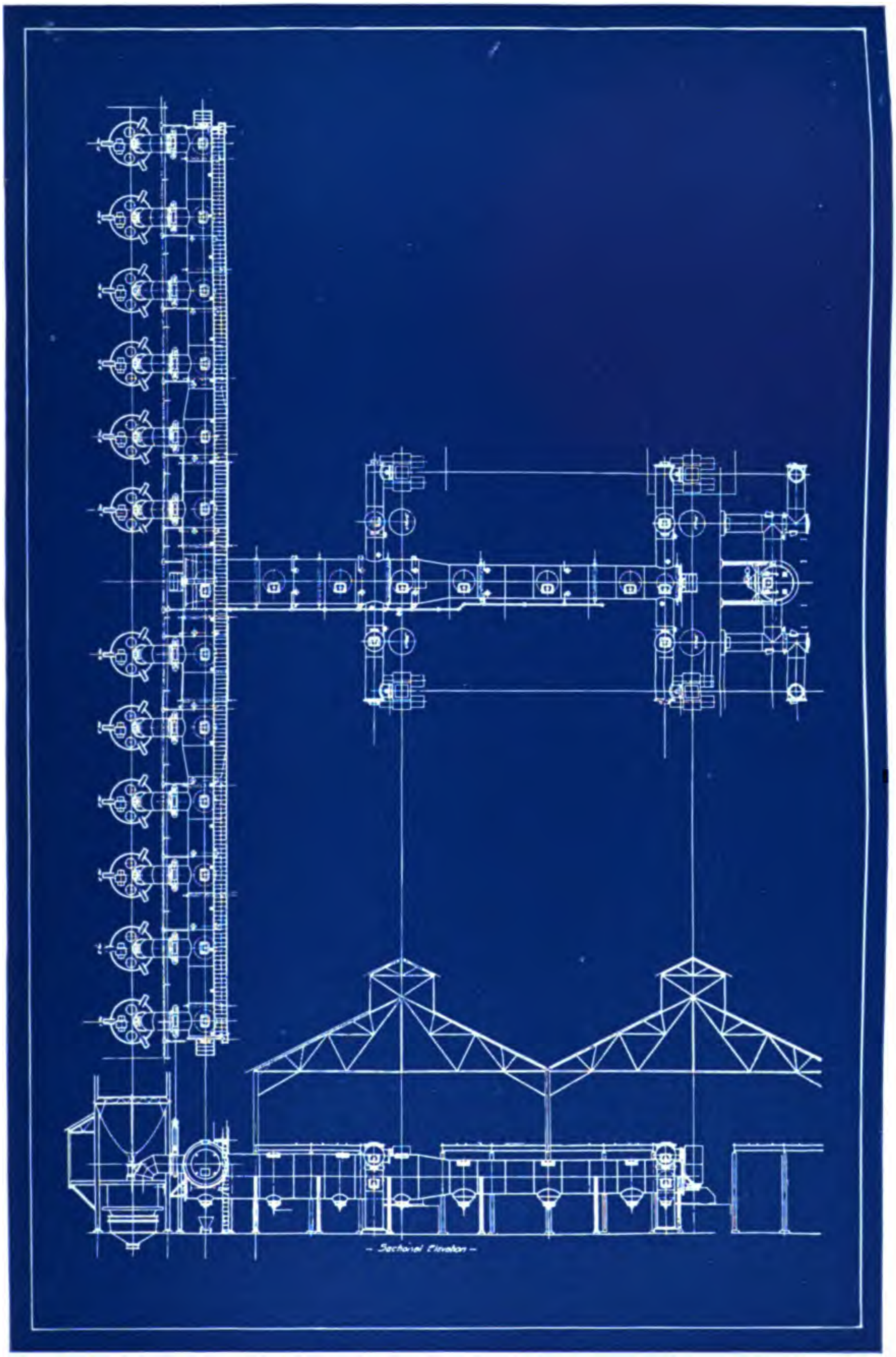


Figure 105—LAYOUT OF GAS FLUE
For a battery of twelve producers delivering gas to steel and heating furnaces

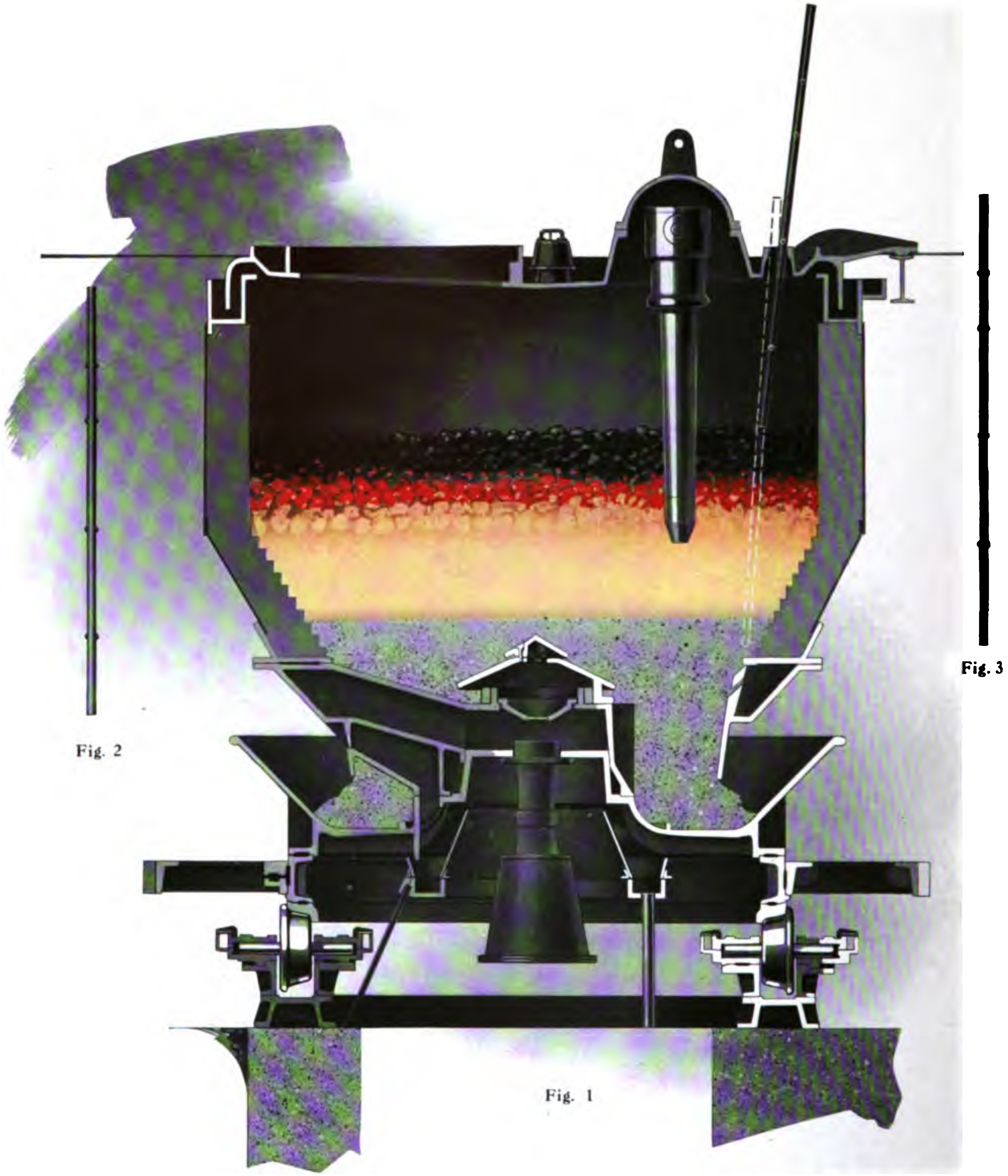


Fig. 2

Fig. 3

Fig. 1

Figure 106—ZONES OF DISTILLATION AND MEASURING ROD

Cross Section of a Wellman (Hughes) Gas Producer, showing the zones of green coal, the distillation and gas making, and pure ashes.

CHAPTER XIX

Operation of Gas Producer

It is the aim of this chapter to reduce the operation to a rule of thumb method which will be of assistance to the Operator or Superintendent and may be applied to every day operating conditions met with in producer practice.

Starting the Producer

A new producer, before being started, should be dried out several days with small fires. This is a precaution which, if properly carried out, will add considerably to the life of the lining. After the producer has been thoroughly dried, all large pieces of wood likely to cause trouble should be removed and the producer filled with ashes to a depth of at least twelve inches over the top of the blower. It is best that a few large clinkers be placed around the openings of the blower to keep them from becoming clogged with fine ashes. These ashes are necessary to protect the metal parts of the producer. They also act as a diffusing medium to distribute the blast over the entire fuel bed thus insuring even combustion.

To start the producer, it is necessary only to level off the ashes, throw in several armfuls of small, dry wood, saturate with kerosene, and light with a piece of waste. After the wood has burned for a few moments, turn on about ten pounds of blast and blow until the wood is well ignited. A small amount of coal can then be dumped and the fires be built up gradually. Care should be taken that the coal is not fed too fast. Allow a good bed of coke to be formed before any attempt is made toward crowding the operation of the producer. One should remember that it takes several hours to get a producer fire built up properly to the point where it is making good gas.

No special attempt need be made at this point to get the fire distributed over the entire fuel bed. It will spread itself later and it is usually better to have a good fire at one point than several small ones scattered over a larger area.

In case it is necessary to stop the producer at any time, the blast should be immediately turned off and never exceed ten pounds during this idle period.

Three Zones

The various zones of the producer are shown in the drawing on page 234. It can be seen that there are three—the ash, the incandescent or the fire zone, and the green coal zone, this last consisting of coal which has not received a sufficient amount of air to become incandescent. This is also termed the distillation zone. The existence of these three zones is a point often overlooked in the operation of the producer.

Measuring Fires

The usual method of measuring the fires is for the foreman to take a rod about five feet long which he inserts in one of the poke holes in the producer top until he establishes the height of the fuel bed. This method is totally inadequate because no attention is given to the depth of the fire zone, the most important point of all in the operation of a gas producer. If the ash zone is allowed to exceed a reasonable limit, say fifteen inches, the fire zone is considerably reduced and it is impossible to carry the proper depth of fire if the ashes are not kept within a reasonable limit.

This tendency of the ashes to crowd out the fire zone makes it possible for the top of the fuel to be at the proper height and yet the fire may be so thin that the gas will be of exceedingly poor quality.

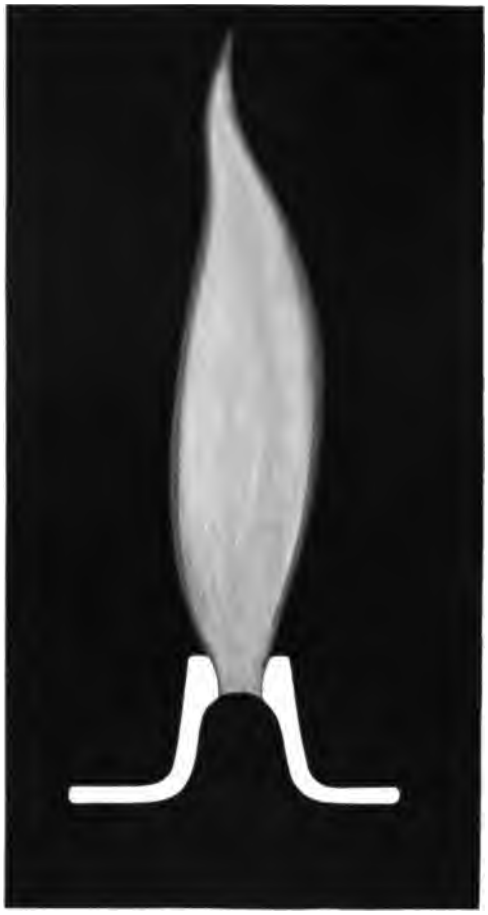


Figure 107—Appearance of Cold Gas Temperature 1000° F. or Less

The only way the fires can be properly measured is to force the rod completely through the fire and allow it to remain long enough to become red hot. After the rod has been withdrawn, it is easy to see the part which has been in contact with the hottest portion of the fire and the part which has been protected by the ashes. Knowing the distance to the blower or the metal parts of the producer, it is a simple matter to tell exactly the depth of the various zones.

A very convenient rod for this work is shown in Fig. 2. This consists of a ¾-inch gas pipe marked into two foot sections by ¼-inch rivets running through the pipe. Any other method of marking may be used which will not be destroyed by the action of the fire or interfere with the passage of the pipe through the fuel bed. A mark is also placed at the height equal to the distance between the blower and the producer top. This indicates the distance the rod should be forced into the producer. Fig. 3 shows such a rod, the method of marking, and its appearance after being withdrawn from the fire. In using the rod, the distance to the top of the fuel bed is first determined. (See Fig. 1). The rod is forced through the fuel bed until the lower end is on a level with the top of the blower and allowed to remain there for two or three minutes. This is usually all the time necessary for the rod to remain in the fire. On being withdrawn, it will be noted that there are two parts which show up distinctly—one a smoky black extending for several feet, and the other a very hot portion usually from 12 to 24 inches in length. This latter indicates the incandescent zone. Below the lower point of this zone and the end of the rod, there is a portion not affected by the heat and it should not be very hot. This is the ash zone and should never be less than 6 inches and seldom, if ever, exceed 15 inches.

Between the highest point of the hot portion of this rod and the distance determined to the top of the fuel, there will be a space of from 6 to 12 inches. This is the green coal zone. If the coal is of a tarry nature, it is possible that this zone will stand out distinctly by a tarry deposit upon the rod which can be readily distinguished from the sooty deposit above this section. The sooty portion of the rod represents the part in contact with the gas.

It is not intended that this method of measuring the fires should be employed more than two or three times per day, depending upon the number of times the fires are cleaned, but this is the only way the ash zone and the fire zone can be measured and the amount of ashes that it will be necessary to remove be determined.

If the fires are measured just before the change of turns twice a day, it eliminates all chance for the men to excuse their own indifference by blaming the other shift for trouble which might be of their own making.

Hot or Cold Gas

The green coal zone mentioned in previous paragraphs may vary with requirements. If it is intended to generate a hot gas, that is gas leaving the producer at a temperature of about 1200° F., the coal zone should not be allowed to exceed 6 to 8 inches. The gas showing when the poke hole cover is removed will be a brownish-black and a small pilot flame or color cone of about 3 inches in length will appear in the center of the escaping gas. If, however, it is desired to generate what is termed cold gas, a deeper layer of coal must be carried over the incandescent fuel. This may be anywhere from 8 to 15 inches depending more especially upon the nature of the fuel. Under these conditions the gas appearing when the poke hole cover is removed will be a bluish-white and the temperature when leaving the producer may be as low as 700° F. This is by far the richest and best gas for most purposes. The hot gas usually carries a Btu. value per cubic foot of about 150, while the cold gas may have a value of 170 to 180 Btu. per cubic foot.

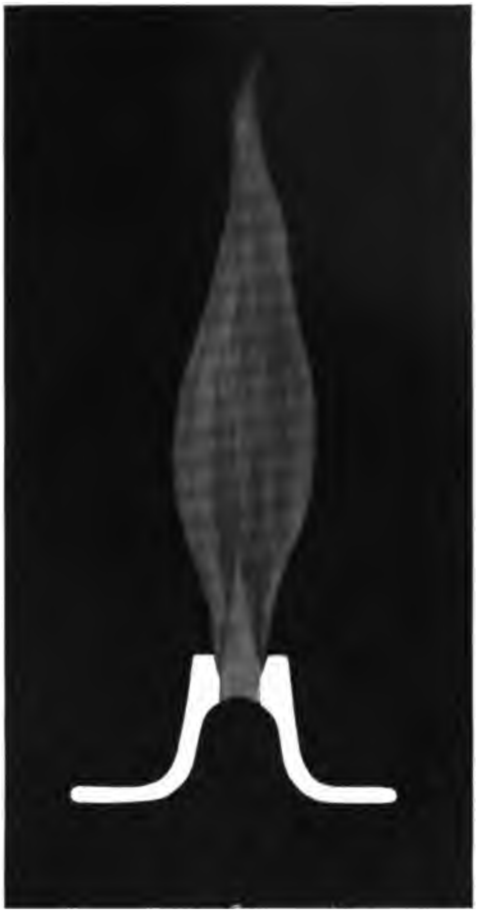


Figure 108—Appearance of Hot Gas Temperature about 1300° F.

Some operators insist that cold gas will not operate efficiently in open hearth furnaces or other places where it is desired to carry a melting temperature. This is a matter open to some discussion. There are, however, several open hearth plants in very successful operation using cold gas by preference.

Points of Interest

Some coals have a tendency to become soft and pasty under the action of the heat in the producer. This restricts the passage of the gas and owing to the fact that the pressure accumulates under the steady blast, the gases will seek channels to break through the resistance of the fuel bed. These points then become excessively hot, melting the ashes and other foreign particles in the coal which form the basis of clinkers.

If the coal in use is of this nature, care should be taken to see that these channels do not form. This can be done by close attention to the stirring and the regulation of the blast or it may be necessary to change the mixture of the blast increasing the proportion of steam to the amount of air blown. This will lower the temperature of the fire and thus considerably decrease the tendency for the fires to clinker. It should be remembered that the change should not be carried to the point where the CO_2 content in the gas becomes excessive or the fires are so cooled that the carbon in the coal is not properly gasified. Either of these items determine a certain amount of loss, but the situation should be considered as a whole and decision made as to whether the stoppage due to clinkering and the extra labor attendant to the same are not more than an offset for the few percentages of the CO_2 or a slightly increased amount of carbon in the ashes.

Cleaning the Fires

It is the usual custom to clean the fires about two or three times a day, depending upon the amount of coal burned and the percentage of the ash in the coal.

It is not necessary that the operation of the producer be discontinued during the cleaning period. The fire should never be lowered more than eight to ten inches during one cleaning period, and coal should be dumped as during the regular period, although usually in smaller amounts. It is better to lower the pressure on the blowers ten or fifteen pounds during this period. If two or more producers are arranged to operate on the same line the other producers should be blown slightly harder during this interval and if this operation is properly carried out, the entire battery of producers may be cleaned without the slightest effect noticed in the operation of the furnaces. During the cleaning period, careful attention should be given to any clinker formations, that are likely to appear on the side wall. These should be broken loose and the side walls kept clean.

Feeding Coal

The proper dumping and distribution of the coal charges have a decided bearing upon the conditions obtained in producer operation. The coal should be dumped in as small quantities as can be conveniently arranged and strict attention should be paid to the color and appearance of the gas which shows whether or not the fuel bed is of the proper thickness.

Operation of Steam Jet Blower

The amount of steam required to blow the producer varies with requirements. If it is necessary to crowd the machine more air is needed to burn the increased amount of coal and as the proportion of steam and air must be maintained, it is only necessary to increase the steam pressure until the proper amount of air is delivered. This in no way affects the quality of the gas if the fires are kept in the proper condition. Gas of just as good quality can be made at 100 pounds pressure as at fifteen pounds—only the volume will be greatly increased and it is possible for the fires to get out of order much more quickly. It is hard to set a definite limit upon the amount of steam required but as a general thing it is seldom necessary to use more than 40 pounds of steam to get the desired results.

Operation of Turbo Blower

The arrangement of turbo and jet blower in combination, calls for a slightly different form of manipulation than for the old simple jet type alone.

To begin with, it is never intended to operate these two systems simultaneously, the only reason for the two systems being for the purpose of reliability, providing means for operating the producer should an accident occur to either of the systems.

The amount of moisture mixed with the blast is always under control, but care should be taken that this is not allowed to become excessive. If the saturation point is allowed to go over 140° to 145° as a usual practice trouble is likely to be encountered by the coal being kept so soft that it will crumble to a fine powder in the producer, and stop the passage of the gas completely. The best results will be obtained with careful operation if the fires are kept as near the clinkering point as possible, except at the

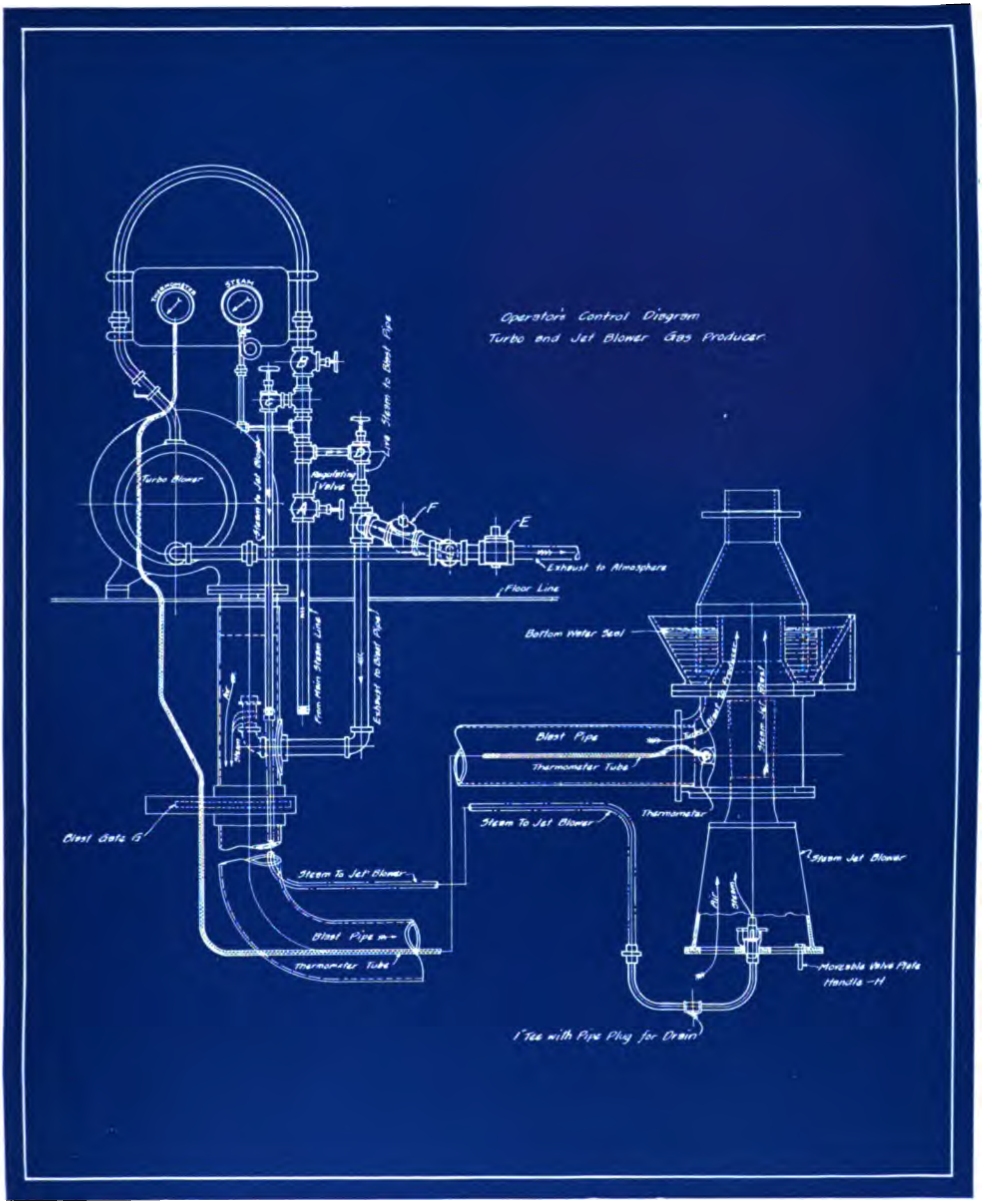


Figure 109—THE WELLMAN GAS PRODUCER TURBO AND JET BLOWER

By these devices air may be delivered to the producer by either the turbo blower or by steam jet blower, enabling the operator to avail himself of either system.

cleaning periods when the saturation point can be raised a few degrees, and brought back to normal as soon as the fires have been cleaned.

For the operation of the turbo blower in starting a producer, the valve plate on the steam jet blower marked "H" on the drawing on page 239, should be completely closed. The blast gate "G" on the blast pipe from the blower should be wide open.

Valves "C," "D" and "F," should be tightly closed, and the valve "E" should be open.

All the regulating for the amount of steam to either the turbo or the jet blowers, should be done by the valve "A." This will give the pressure, at which the producer is being blown, on the gauge, and under no conditions should the valves "B" or "C" be used to regulate the blowers.

With valves set according to the above instructions the action is as follows:

The steam from the main line is regulated to the turbo by the valve "A." The pressure on the producer is registered on the steam gauge. After passing the valve the steam flows through the turbo and out the exhaust pipe through the valve "E" to the atmosphere.

Under these conditions no steam is being delivered to the producer which is being blown with pure air alone. During ordinary operating conditions, with this arrangement, the fires would become excessively hot and likely to cause clinker trouble, but for starting a new producer if no steam is injected with the air the fires can be brought up to the proper working conditions much more quickly than with the old jet type of blower.

After the fires have attained the proper depth and the producer is making gas, the valve "F" should be opened and valve "E" closed, and during ordinary operating conditions it should never be necessary for these valves to be again disturbed.

With this arrangement of valves the exhaust steam from the turbo is mixed with the air going to the producer, and the percentage of steam obtained will be registered on the thermometer gauge.

Usually the amount of exhaust steam is not sufficient to provide the necessary moisture which keeps the fires properly softened. To obtain this required amount it is necessary to use live steam. This is obtained by means of the valve "D." A slight opening of this valve will allow the live steam from the main line to pass directly into the exhaust line from the turbo and with this arrangement the blast temperature can be brought to any point desired.

If it is desired to operate the jet blower alone the valve plate "H" should be opened. Valves "B," "D" and the blast gate "G" should be closed. Valve "C" should be opened wide and the regulating of the blower done from valve "H." With this arrangement of valves the operation will proceed exactly as for the old jet blower.

Cooling Water

In starting a new producer the top plate has a tendency to run hot and will usually require about all the water that can be applied through the three connections furnished. After a few days the top plate becomes coated with carbon and the quantity of the water can be considerably reduced. The overflow from the poker is usually sufficient for all purposes and this amounts to approximately fifteen to twenty gallons per minute.

If for any cause the water pressure should be lost so that no water will flow through the poker the producer should be immediately shut down and every effort made to keep the poker cool by means of an emergency line of steam or air. Caution should be exercised in starting the water to flowing through the system because if a large amount of cold water is allowed to strike the poker there is danger of the point breaking, making its replacement necessary.

The life of a poker tip is from six months to a year, depending considerably upon the condition in which the operator has kept his fires. This tip is a separate point screwed into the main barrel of the poker while the latter is heated to a cherry red color. This method of applying new tips should be used to prevent their working loose under the action of the fire. It is good policy to have a spare poker and trunnion ready for immediate use and the entire poker and trunnion changed if it is necessary to make a replacement during the operating period. This operation should not require more than twenty minutes.

Shutting Down

In most installations there are periods when the furnace is down for repairs. This time should be taken to clean out the producer completely. The side walls should be cleaned, the blower and blast boxes cleaned out and any mechanical part needing attention should be repaired. This procedure, if carried out, will never amount to a great deal of labor and it will be more than repaid by the increased reliability of the machine and the success attained in its use.

Gas Making Conditions in the Producer

The quality of producer gas depends upon its combustibles. The quantity and character of these are affected by the operating conditions within the producer. During the ordinary operation of a battery of Wellman producers in a steel mill seventy-five tests were made yielding data given in table and diagrams on pages 242 and 243. Briefly stated the following conclusions may be drawn from these tests:

To make a rich gas, high in British thermal units, the ashes should be maintained at a height of a foot above the blast cover.

The combustion zone should be confined to a thin fire, approximating six to eight inches in thickness.

The green coal zone in which distillation of hydrocarbons (which enrich the gas) occurs should be kept from twelve to eighteen inches thick.

Under these conditions the pressure of steam used for the blast should be twenty-three pounds per square inch.

Such operation produces gas in which a greater part of the calorific energy is due to its combustibles, rather than to its sensible heat. This is desirable as the heat losses during transmission to the point of consumption are less with a cool gas as compared with a highly heated gas.

The rate of gasification was 24.9 lbs. of bituminous coal per square foot of producer cross section per hour or 1960 lbs. per producer per hour, as the consumption of gas did not require a higher rate at the plant under consideration.

The pitch of the curves of the diagram, together with the heat value of the gas, indicate what results will follow a departure from the most favorable operating conditions. See pages 242, 243 and 244.

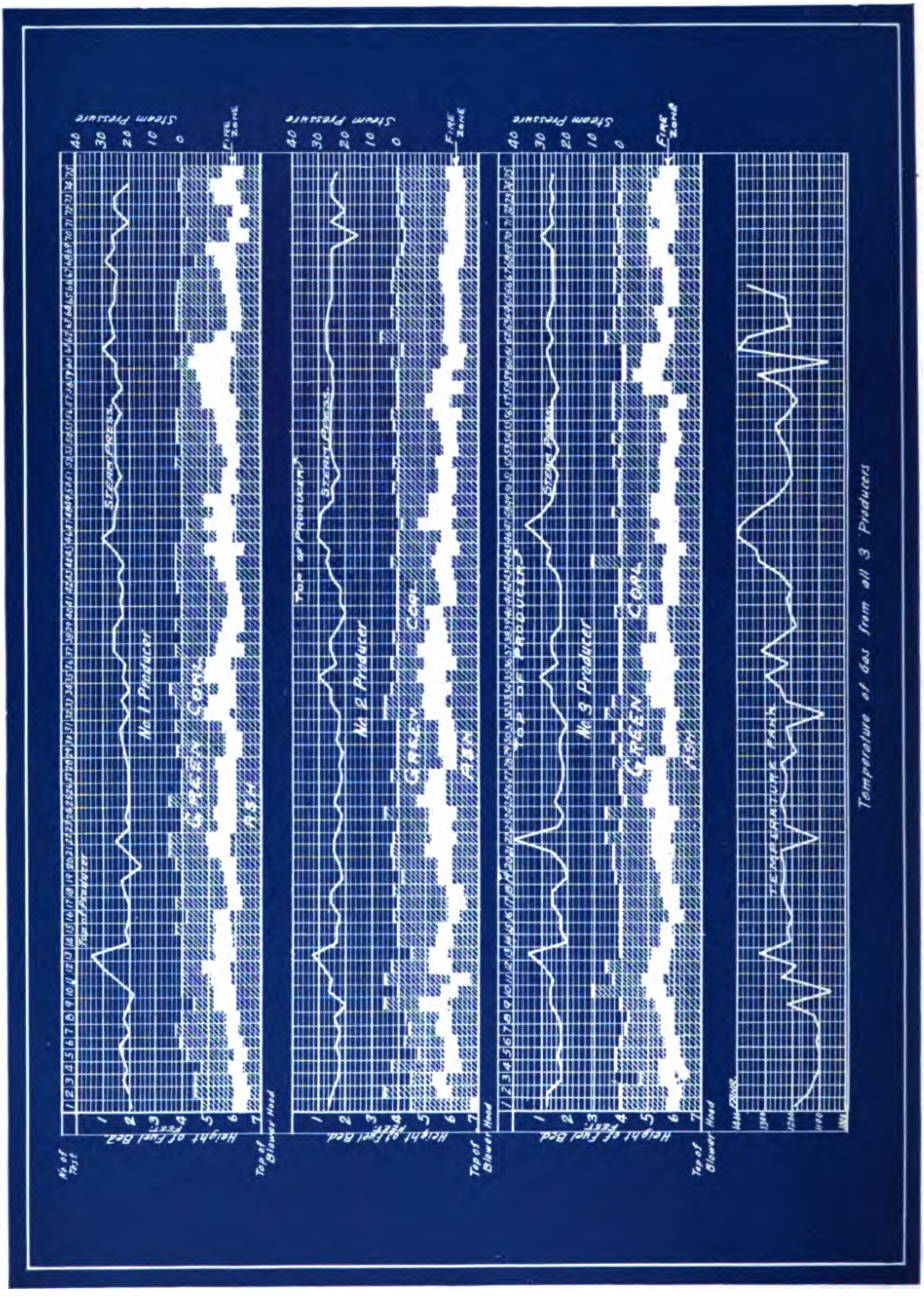


Figure 110—GRAPHICAL LOG OF WELLMAN GAS PRODUCER TESTS

Table No. 70

Gas Analysis
Corresponding to Graphical Log of Tests

No.	CO_2	C_2H_4	O_2	CO	CH_4	H_2	Low Values B.T.U. In	
							1 cu.ft.	Gas
1							32° F.	62° F.
2	6.6	.4	0	22.0	4.4	16.6	171.4	160.9
3	6.0	.4	0	23.4	3.6	12.4	156.2	146.6
4	6.4	.3	0	23.2	5.4	13.2	173.6	162.6
5	5.3	.4	0	24.4	3.4	13.8	161.8	151.9
6	5.7	.3	0	24.0	4.0	12.2	159.9	150.3
7	5.3	.3	0	23.2	4.2	12.3	159.5	149.6
8	6.6	.3	0	22.6	3.6	10.8	146.4	138.3
9	6.8	.2	0	21.4	4.2	11.8	150.3	136.1
10	7.6	.2	0	20.2	4.8	12.4	153.8	143.4
11	6.3	.3	0	23.8	3.8	11.6	155.6	146.1
12	4.0	.3	0	23.8	3.0	11.0	146.2	137.2
13	7.2	.3	0	20.6	4.4	10.6	147.6	138.5
14	6.2	.3	0	21.0	3.2	11.4	139.8	131.2
15	8.3	.3	0	21.6	3.8	9.8	142.9	134.2
16	6.7	.3	0	24.6	3.6	10.4	154.7	143.6
17	6.3	.3	0	22.8	3.8	12.4	154.5	145.1
18	6.7	.3	0	23.4	4.0	11.0	154.4	145.0
19	6.9	.3	0	22.2	4.0	12.2	153.9	144.4
20	5.0	.3	0	22.8	4.4	14.0	165.0	154.8
21	7.0	.3	0	22.6	4.0	11.8	153.0	144.6
22	9.5	.3	0	19.6	4.0	10.6	139.0	125.4
23	6.5	.3	0	22.4	4.0	11.6	152.8	143.4
24	6.7	.3	0	23.0	3.4	14.6	157.8	148.0
25	6.5	.3	0	23.0	3.4	14.6	157.8	148.0
26	6.2	.4	0	21.8	3.9	13.2	156.0	146.4
27	6.3	.3	0	23.8	3.8	14.6	164.3	154.2
28	6.4	.3	0	22.0	4.0	12.2	155.1	143.8
29	6.2	.3	0	23.4	3.4	13.8	156.8	143.9
30	5.5	.3	0	24.4	3.6	13.0	161.7	150.0
31	6.3	.3	0	23.0	3.6	13.0	156.9	145.5
32	6.0	.3	0	26.0	3.0	11.8	155.9	146.4
33	7.0	.3	0	22.0	4.0	14.2	159.0	149.2
34	6.9	.3	0	22.6	3.0	12.4	145.2	137.2
35	7.3	.3	0	22.4	3.8	13.8	157.3	147.6
36	7.7	.3	0	20.2	3.6	12.2	155.2	143.4
37	7.5	.3	0	20.4	3.6	15.2	154.6	143.2
38	7.5	.3	0	22.0	4.4	13.4	165.0	150.7
39	5.6	.3	0	24.6	3.8	14.8	167.6	157.3
40	6.0	.3	0	23.8	4.2	12.4	161.8	151.8
41	5.0	.4	0	23.4	3.4	13.6	157.8	148.1
42	6.8	.3	0	23.8	4.0	13.4	162.8	152.7
43	8.0	.3	0	20.2	3.0	12.2	157.5	129.0
44	8.6	.3	0	19.6	3.6	13.8	155.9	136.8
45	7.5	.3	0	21.2	3.8	13.4	152.1	142.7
46	7.2	.3	0	20.6	3.8	10.2	147.0	132.1
47	7.8	.3	0	20.4	4.4	11.2	148.7	139.6
48	8.8	.3	0	21.2	3.8	13.8	153.2	153.7
49	7.3	.3	0	21.6	3.6	15.6	158.0	148.1
50	6.5	.3	0	23.4	3.0	13.4	151.8	142.5
51	6.3	.3	0	23.2	3.8	13.2	153.2	148.5
52	5.8	.4	0	23.4	3.2	13.0	153.5	144.7
53	5.7	.3	0	23.0	3.0	12.2	148.3	137.9
54	6.4	.4	0	23.4	4.0	12.2	158.1	150.8
55	6.4	.3	0	23.8	3.4	14.6	158.5	150.6
56	6.2	.4	0	22.8	3.0	14.2	157.1	144.2
67	6.3	.3	0	22.8	3.4	14.6	160.1	147.4
58	6.7	.3	0	23.2	4.4	11.4	158.7	149.0
59	7.0	.3	0	21.4	3.2	12.0	142.9	134.1
60	6.5	.3	0	22.2	4.0	16.0	164.9	154.7
61	6.2	.3	0	22.4	4.0	10.2	148.7	139.7
62	7.5	.3	0	20.6	3.6	11.6	142.9	134.1
63	5.5	.3	0	23.2	3.2	13.6	153.6	133.8
64	6.2	.4	0	23.0	3.6	12.6	157.0	145.9
65	6.5	.3	0	22.8	3.4	12.8	155.3	142.5
66	6.0	.4	0	23.8	3.8	12.4	157.5	149.7
67	6.0	.4	0	23.2	4.0	12.8	160.6	150.7
68	7.5	.3	0	21.8	3.0	10.2	142.7	128.7
69	6.5	.3	0	22.4	3.4	13.6	152.9	143.4
70	7.1	.3	0	21.6	4.0	12.6	153.0	143.6
71	6.9	.3	0	22.0	3.8	12.0	157.0	141.4
72	6.3	.2	0	23.0	3.6	13.0	153.5	144.8
73	6.3	.3	0	22.4	3.8	14.2	158.4	150.7
74	5.2	.4	0	23.0	3.8	14.2	162.0	152.1
75	5.3	.3	0	22.6	3.6	13.6	154.4	145.9
Av.	6.5	.3	0	22.4	3.8	12.8	153.1	144.7
						High Values	165.1	157.3

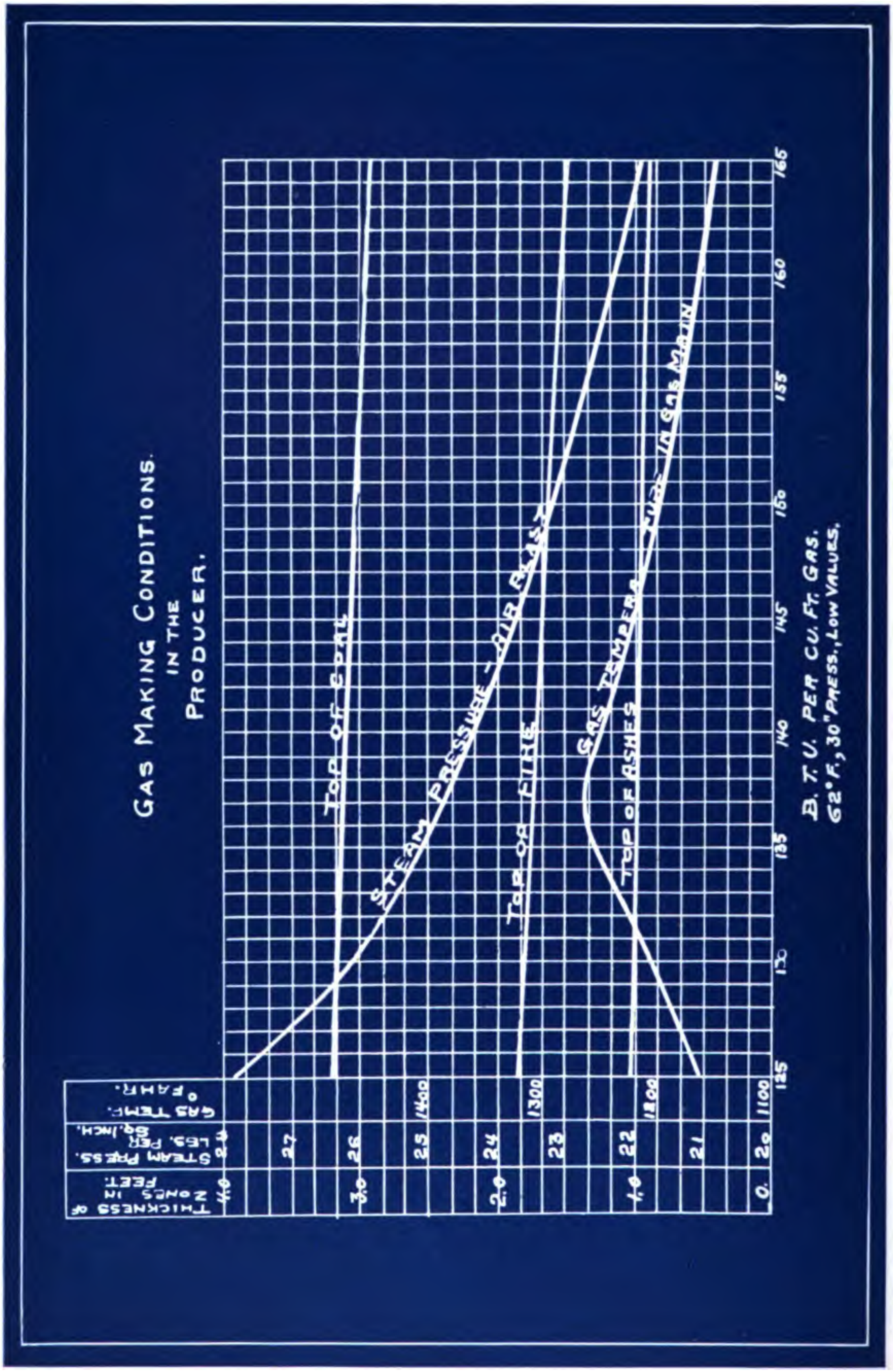


Figure 111—GAS MAKING CONDITIONS IN PRODUCER

Wellman Gas Producer Installation Data

It should be remembered that producer gas is handled in large volumes. This fact makes it unnecessary to provide for a fine adjustment of the regulating valves.

The flues should be of ample size to keep the velocity of the gases as low as possible.

A speed of 10 ft. per second should never be exceeded and to this required area, a 20% addition should be made to allow for the accumulation of soot.

Producer gas carries a certain amount of dirt and tar which will adhere to the sides of the flues, particularly where the gas makes a right angle turn. Provision should be made to remove this deposit periodically, usually about once a week. The plant should be so constructed that the flues may be opened at points throughout its entire length and the deposit burned or blown out either with steam or air; air being the better when available.

The draft for burning out the flues is usually provided by connecting the stack of the furnace directly with the flues by means of a by-pass of ample size, which of course must be kept closed during operation.

The view on page 233 shows the flue system for 12 producers attached to zinc furnaces. In this case, provision was made to clean the flues during the operation. A study of the plan will show the method adopted.

As a result of this arrangement, this plant has been in continuous operation for several years, and at no time has it been necessary to delay the operation of the furnace for the purpose of cleaning the flues.

This plan illustrates a general layout for a three furnace open hearth steel plant. All the important points are well provided for. The coal is deposited in a hopper under the track, crushed and discharged into a bin and distributed by a scale larry car to hoppers over the different producers. The ashes are collected by a hopper car under the producers and then elevated to a car on the track.

The gas flues are accessible throughout their entire length and, for this reason, ample provision can be made toward keeping the flues clean.

Local conditions determine the character of construction, but these views are good illustrations of up-to-date practice and contain many points which should be of value to engineers, figuring on new installations.

In actual furnace operation, the temperature of the gas assists, to a considerable degree, toward obtaining the desired temperature, but when this sensible heat exceeds a certain point, the heating value of the gas begins to be destroyed. For this reason, the temperature of the gas leaving the producers should never exceed 1300° F. For zinc and heating furnaces of all types, it is better to keep this temperature as low as possible, usually varying from 600° to 900° F.

Producer gas is seldom carried for a distance of over 400 to 500 ft. owing to the difficulty of getting sufficient draft to maintain the proper flow of gas.

If these distances must be exceeded, the gas is usually cleaned and forced to its destination by means of exhausters.

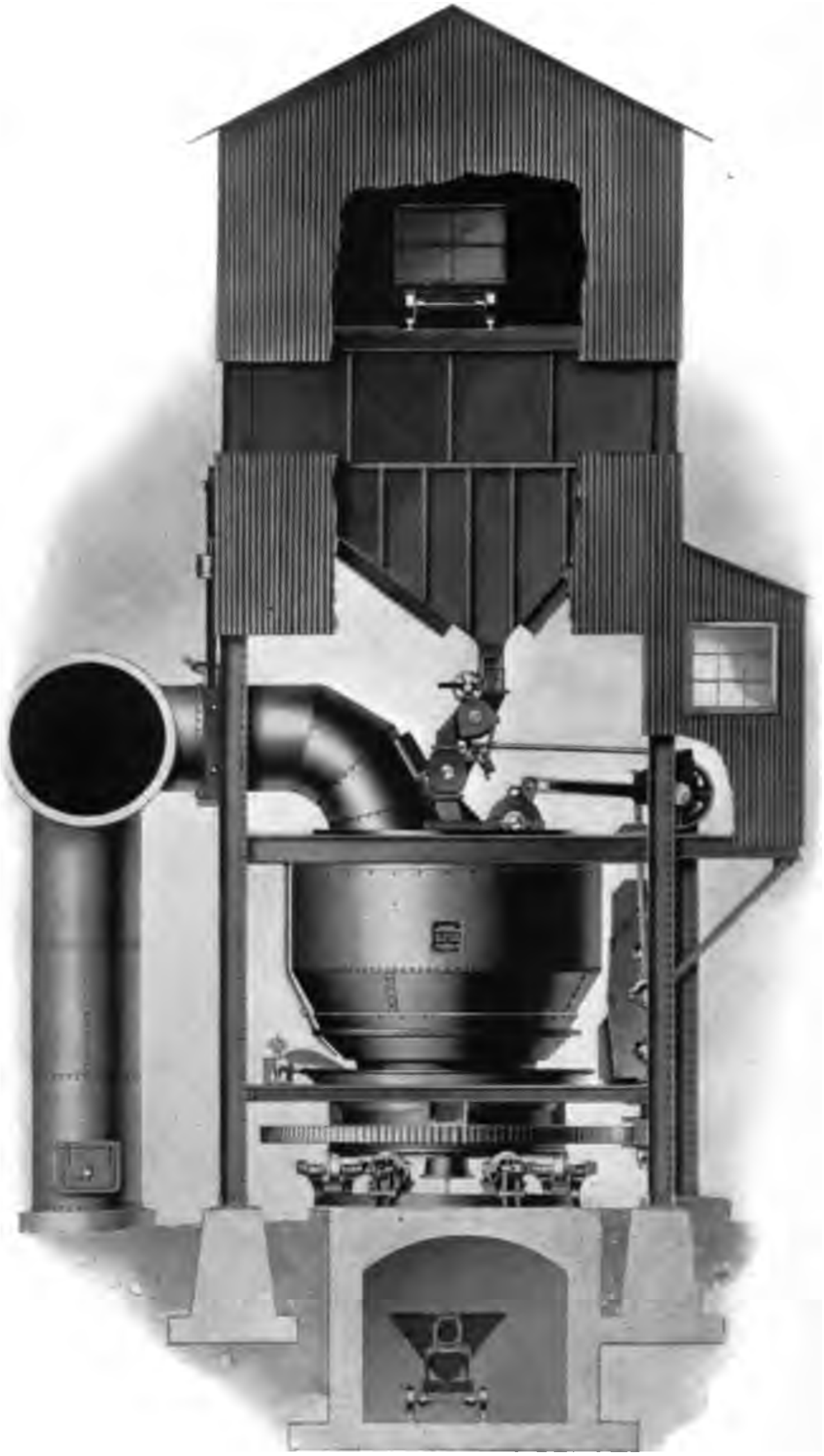


Figure 112—CROSS SECTION OF A TYPICAL PRODUCER HOUSE
Attendance of operatives and manual labor is reduced to a minimum as the mechanical production of gas reaches its maximum development in a Wellman designed and built installation.

CHAPTER XX

Specification for Wellman Gas Producer with Heavy Duty Mechanical Feed

(Patented)

Type AP

For the convenience of those preparing specifications for gas producers the following form is given:

DRAWING:

The general construction and principal dimensions are shown by Drawing No. 54741, (Figure 94 pages 212 and 213) which accompanies and forms a part of this specification.

GENERAL DESCRIPTION:

The producer, with the exception of the top plate, rests upon a cast iron base plate secured to the foundation. Mounted on this base plate are six steel casting brackets carrying six chilled cast iron conical track wheels with their shafts and bearings.

The rotating portion of the producer is supported by these wheels. A hard cast steel ring resting upon the upper treads of these wheels forms a track on which is mounted a steel casting girder ring, to which is connected the cast iron revolving gear and the cast iron water-seal ash pan.

Mounted upon the center of this ash pan is a cast steel three-arm spider and blast ring which supports the producer shell and brick lining. The arms of this spider are of box section, forming ducts for conveying a portion of the blast from the center of the producer to an outside circular distribution ring.

The blast enters the fuel zone through a small hood in the center of the producer, and through a series of slots on the inside of the blast ring adjacent to the brick lining, giving an even distribution of blast throughout the whole mass of fuel. This ring has a depending flange which forms a water-seal in the ash pan.

Resting upon the blast ring is a circular steel casting flange to which the tapered section of the producer shell is secured. The shell is 11 ft. 6 in. diameter, made of 5-16 in. steel plate. A cast steel trough for the upper water-seal rests upon and is attached to the shell.

The producer top is enclosed by a water cooled steel casting cover plate having three lugs resting upon the building framework. The outer edge of the top casting is formed into a flange turning downward into the water-seal trough, which makes a gas-tight joint.

Upon this top casting are mounted the two eccentric coal feeds and the poker with its trunnion bearings, a vertical flange being provided for the gas outlet. A suitable number of bushed hand poke holes are provided in the top casting.

Mechanical Coal Feeds

The Wellman mechanical gas producer is fitted with a set of two Wellman heavy duty mechanical coal feeds. The two feeds are placed on the top plate at different distances from the center.

Each feed consists of two elements. The first is the measuring wheel—a variable speed four-arm vane—regulating the amount of coal discharge. The other element is a five pocket feed valve, revolving at a constant speed in a machined seat. This device feeds the coal at a speed proportioned to the rate of gasification. At the same time it prevents gas leakage. For every 9½° of rotation of the producer, coal is discharged from each feed. As the feeds discharge alternately there will be a discharge of coal every 4¾° of revolution. This insures a practically continuous flow of coal into the producer.

The upper measuring wheel revolves in an upward direction with reference to the main body of the fuel. This lifting or shoveling effect keeps the down-coming coal loose and free from packing tight in the downtake.

Grinding or crushing of the coal is avoided and a positive feed regulation is obtained dependent upon the speed of the measuring wheel. Nor does grinding or crushing occur on the upper half of the measuring wheel, as clearance is provided between the wheel and the case.

The case has large openings for inspection and for the removal of foreign matter. Every part of the feeds is entirely accessible. Should it be necessary to take out any part above the valve seat, this may be done without disturbing the balance of the feeder. A clay or sand sealed damper in the valve seat casting will shut off the feed from the producer when closed. With this arrangement it is possible to shut off the gas from a feed unit and take out the lower feed valve. This operation may be accomplished by the removal of two bolts and the pin connecting the pawl plates to the connecting rod. Meanwhile the producer is kept in operation with the other feed.

There is a small poke hole in the lower part of valve seat casting through which tar and crusts which sometimes form on the sides of the discharge openings may be loosened with a bar. This hole is closed with a tapered plug which is easily removed.

A counterweight deflector plate is hung above the feed valve. This guides the coal into the valve pockets and prevents the pockets from becoming overloaded. As the valve turns, there is provision made for reserve displacement which allows the coal to fall back into the valve pocket. Thus any protruding lump passes the shear point without obstruction unless it is excessively large.

A water drip lubricator moistens the valve seat and keeps the tar plastic and the valve seat lubricated.

The feed is driven from an eccentric common with the poker. The connecting rod to the feed is equipped with a shear pin release to protect the machine from possible damage in event of foreign matter becoming caught in the mechanism.

The movable parts of each feed are driven from a common rocker shaft. The speed of the upper measuring wheel is regulated by means of a traveling limit and hand wheel which regulates the throw of the driving pawls. With this arrangement the amount of coal feed is under absolute control.

The entire construction is extremely rigid and simple—ensuring a long life to the mechanism, a minimum of attention and repair.

GEARING:

The horizontal gear for revolving the producer is rotated by a pinion mounted on a vertical shaft carried in a suitable cast steel step bearing, and connected to the motor through spur and bevel gear reductions. Extra heavy cast iron brackets supporting this gearing are mounted on a substantial structural steel machinery column secured at its lower end to the foundation, and at its upper end to the producer top and building.

There is connected to one of the gear reductions an eccentric and connecting rod driving a ratchet wheel carrying a crank with another connecting rod which vibrates the reciprocating poker. A third connecting rod from the top of the ratchet operates the mechanical feed.

POKER:

The poker consists of a hollow steel casting with a removable tip. The entire poker and trunnion are water cooled. A shearing pin in the connecting rod provides against damage to the mechanism in case of emergency. The cooling water is conveyed from the source of supply located adjacent to the producer, to the poker, overflowing into the water cooled top plate, thence consecutively into the upper water-seal, the lower water-seal, and to the waste.

BLOWER:

Attached to the base of the ash pan, and leading into the hollow distributing spider and blast ring, is a central conical blast inlet to which is connected a steam blower of the injector type. This blower has a bronze swivel nozzle.

ASH PLOWS:

Adjacent to and extending into the ash pan are the ash remover and the ash plow. The former draws the ashes from the center of the producer to the outside edge of the ash pan, where the latter discharges them into a suitable pocket or opening provided in the ash floor.

These mechanisms are provided with an automatic trip which throws them out of use after the completion of one revolution of the producer. To remove more ashes they must then be reset.

GEAR GUARDS:

All gears, where exposed and liable to injure workmen, are protected by removable gear guards.

GAS OUTLET:

A vertical flange cast in the top plate provides a connection for the gas outlet.

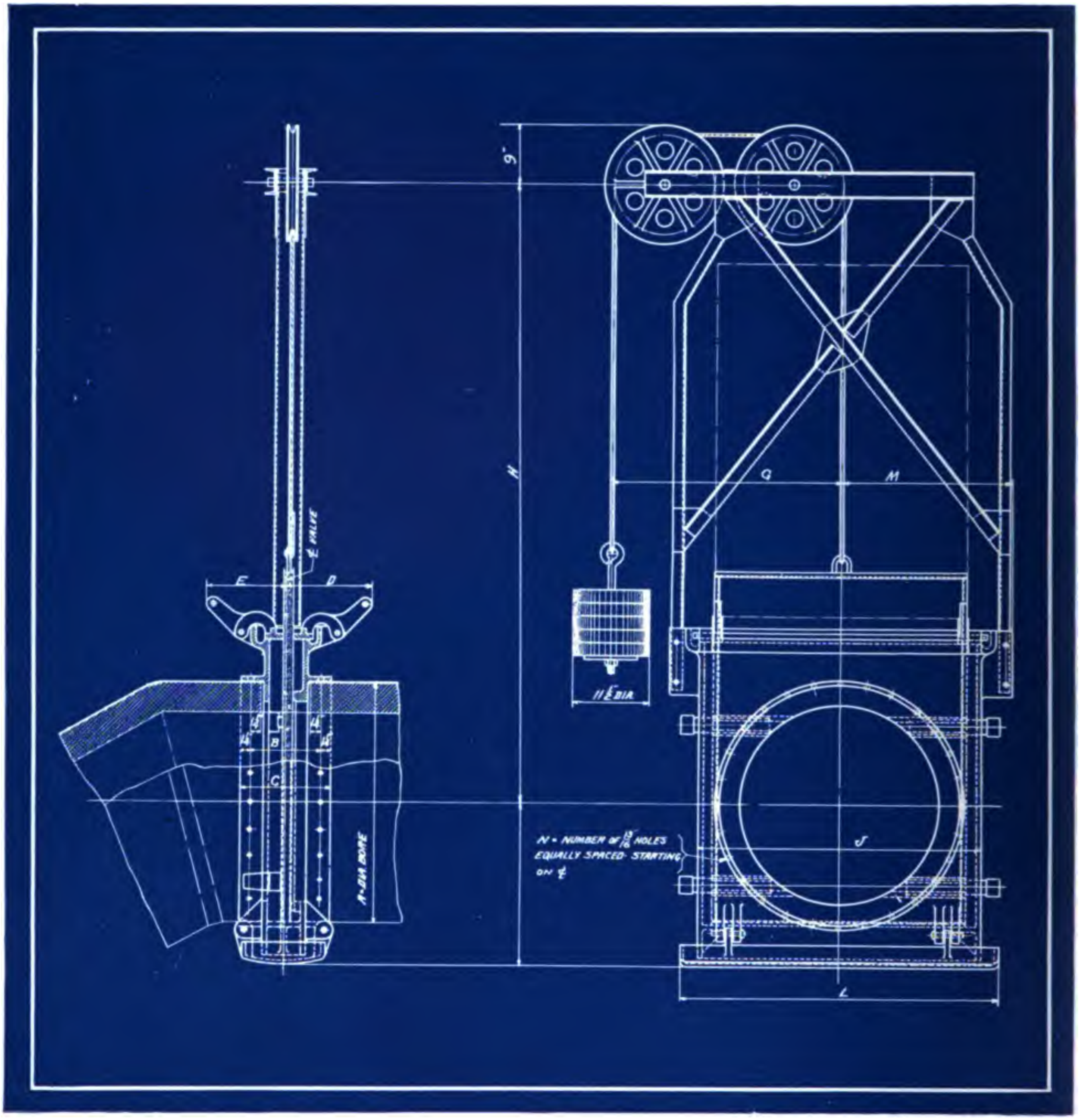
FOUNDATION AND BRICKWORK:

The purchaser shall furnish the foundation, foundation bolts and washers, brick lining and superstructure upon which the producer rests. Hand made, hard burned fire-brick should be used for the lining. Standard shapes are used, the quantity required being specified on the drawing.

WORKMANSHIP AND MATERIAL:

The workmanship and material entering into the construction of this machine are first class in every respect. All of the parts subject to excessive strain or severe service are made of steel castings as indicated by the drawing. All bearings have caps, and are lined.

View in Gas Producer Plant Showing Flues



SIZE	A	B	C	D	E	G	H	J	K	L	M	N
36	36½	12	14½	12¾	12	34½	96	42½	24½	48	26	28
42	42½	12	14½	12¾	12	37½	105	48½	27½	54	29	32
48	48½	12	14½	12¾	12	40½	114	54½	30½	60	32	36
54	54½	12	14½	12¾	12	43½	123	60½	33¾	66	35	40
60	60½	13	15½	13¾	13	46½	132	66½	37	72	38	44
66	66½	13	15½	13¾	13	49½	141	72½	40	78	41	48
72	72½	13	15½	13¾	13	52	148	78½	43⅛	84¾	44	56

Figure 113—THE W-S-M HIGH TEMPERATURE SHUT-OFF VALVE

This valve is used in gas main and exhaust flues. The valve plate is of a highly refractory mineral worked on and burned to an interior steel mesh carried on the surrounding valve plate frame.

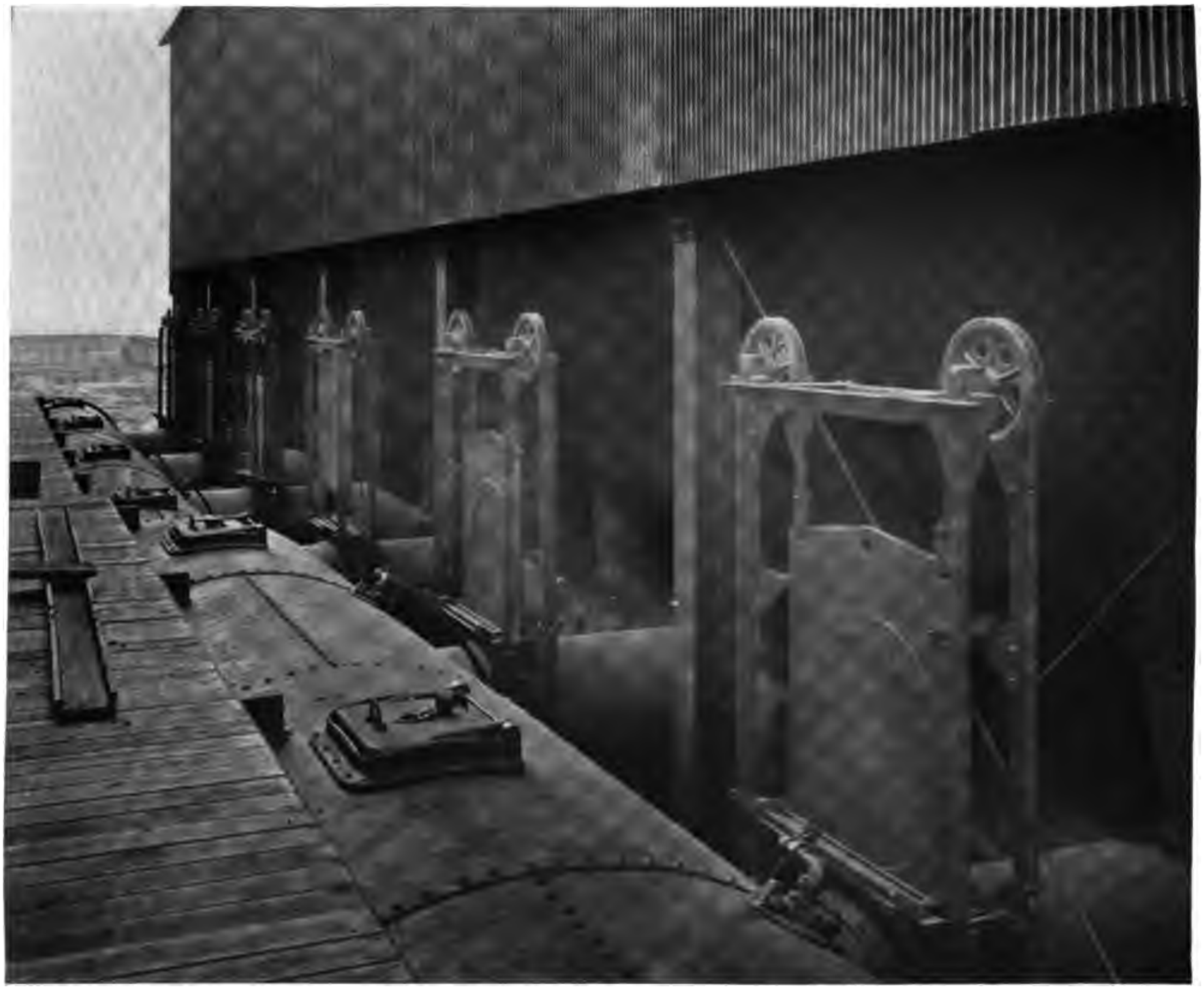


Figure 114—A LARGE GAS MAIN

Taking gas from a battery of producers. A Wellman shut-off valve cuts off each producer from the main when it is taken out of service. The gas main is provided with numerous explosion and clean out doors.

W-S-M Vertical Shut-off Valve

The old method of shutting-off an individual producer by means of a sand damper was a continual source of annoyance. The W-S-M Shut-off Valve overcomes all the objections and dangers. This damper consists of a heavy steel casting which has the necessary flanges for connection to the gas outlet neck and the main gas flue. On the inside of this casting is a machined valve seat while on the top and the bottom are full width openings with hinged covers. The top cover is in two pieces and is hinged to permit the introduction of an asbestos valve plate reinforced by steel bearing plates. The bottom cover is so hinged that it may be dropped from one side to permit the easy removal of tar or foreign matter. By means of four large keys, this asbestos plate may be wedged firmly against the machined seat forming a gas-tight joint. Both top and bottom cover plates are designed so that they may be sealed with clay.

The valve-plate may be raised or lowered by means of sheaves and counter-weights mounted on a structural frame on the valve casting.

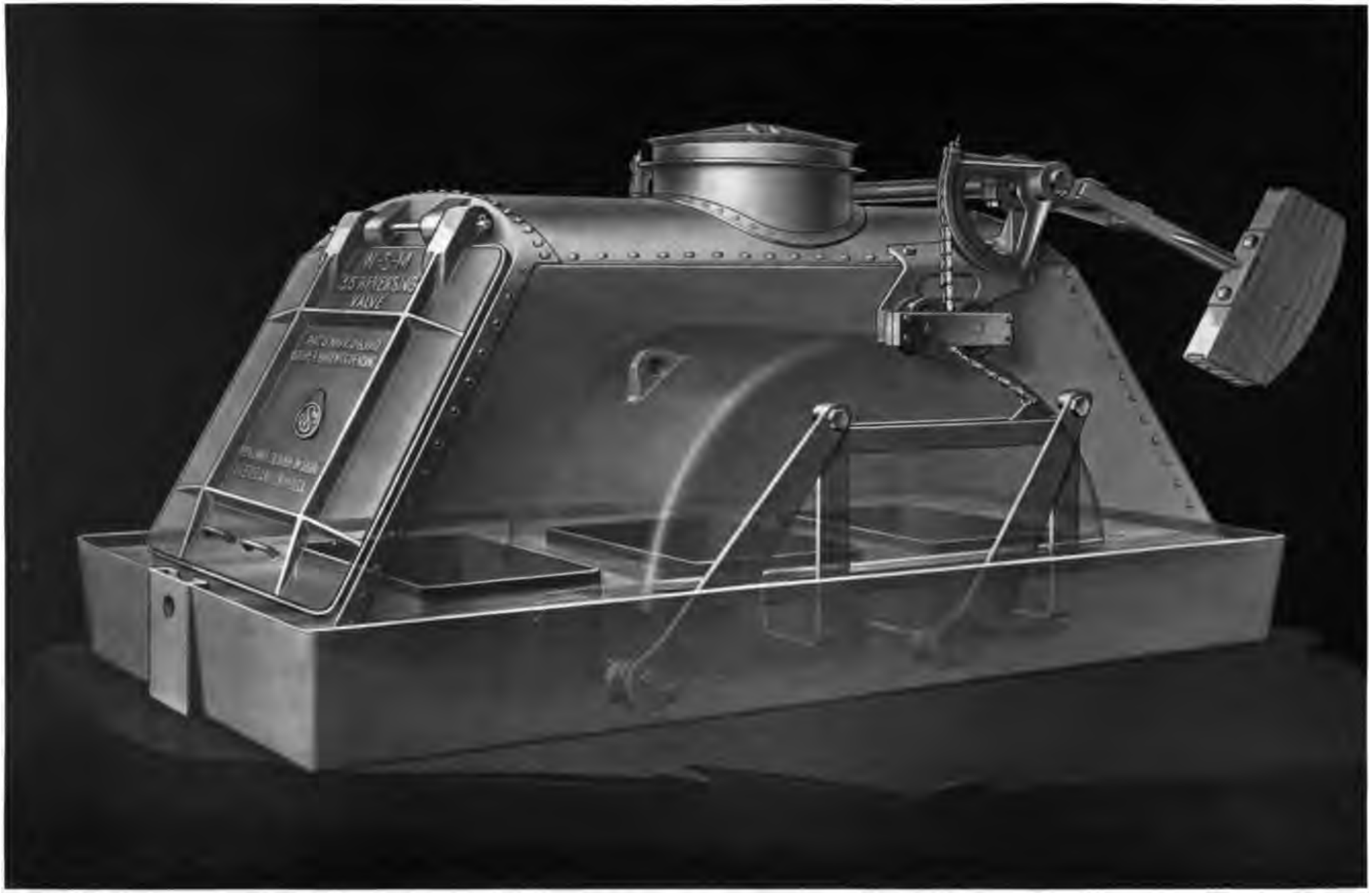


Figure 115—PHANTOM VIEW OF W-S-M REVERSING VALVE

As will be seen in this phantom view the W-S-M valve consists of an outer casing, a base with three ports, a hood to connect two ports, counterweights for the hood and operating mechanism.

CHAPTER XXI

Gas Reversing Valves and Chimney Dampers

In the operation of any gas fired furnace, it is highly desirable that the valve controlling the direction of the flow of gas shall operate rapidly and easily. The new W-S-M gas reversing valve placed on the market in February, 1919, fulfills these requirements. That the conditions have been ideally met is evidenced by the fact that a thirty-six inch hand operated valve can be reversed in from three to seven and a half seconds with a pressure of not over twenty-five pounds. This is accomplished by a perfectly balanced hood and counterweights.

An equally important feature is that, in this new design, the operating mechanism is outside of the casing where it is easily accessible and always cool.

Detail Description of W-S-M Valve

The general design and construction of the W-S-M valve are clearly shown in the phantom view. It is seen to consist of an outer casing, a base with three ports, a hood to connect two ports, and the operating mechanism.

The center port is connected to the chim-

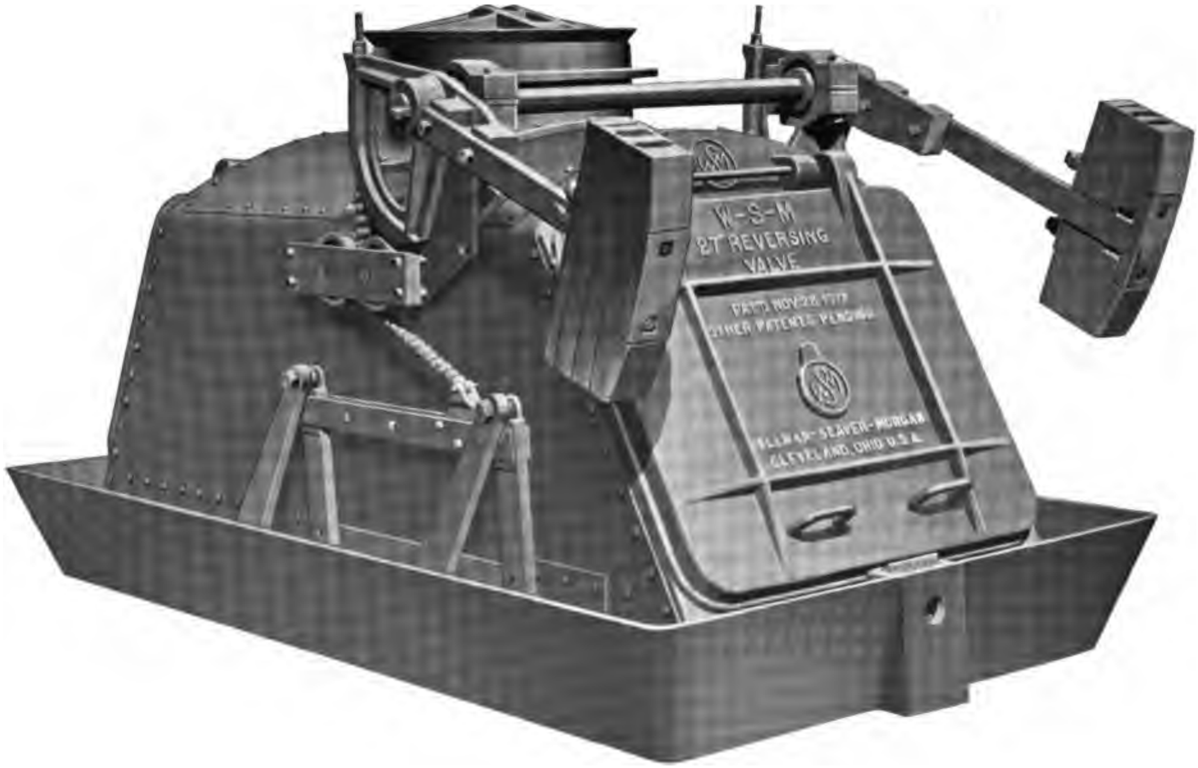
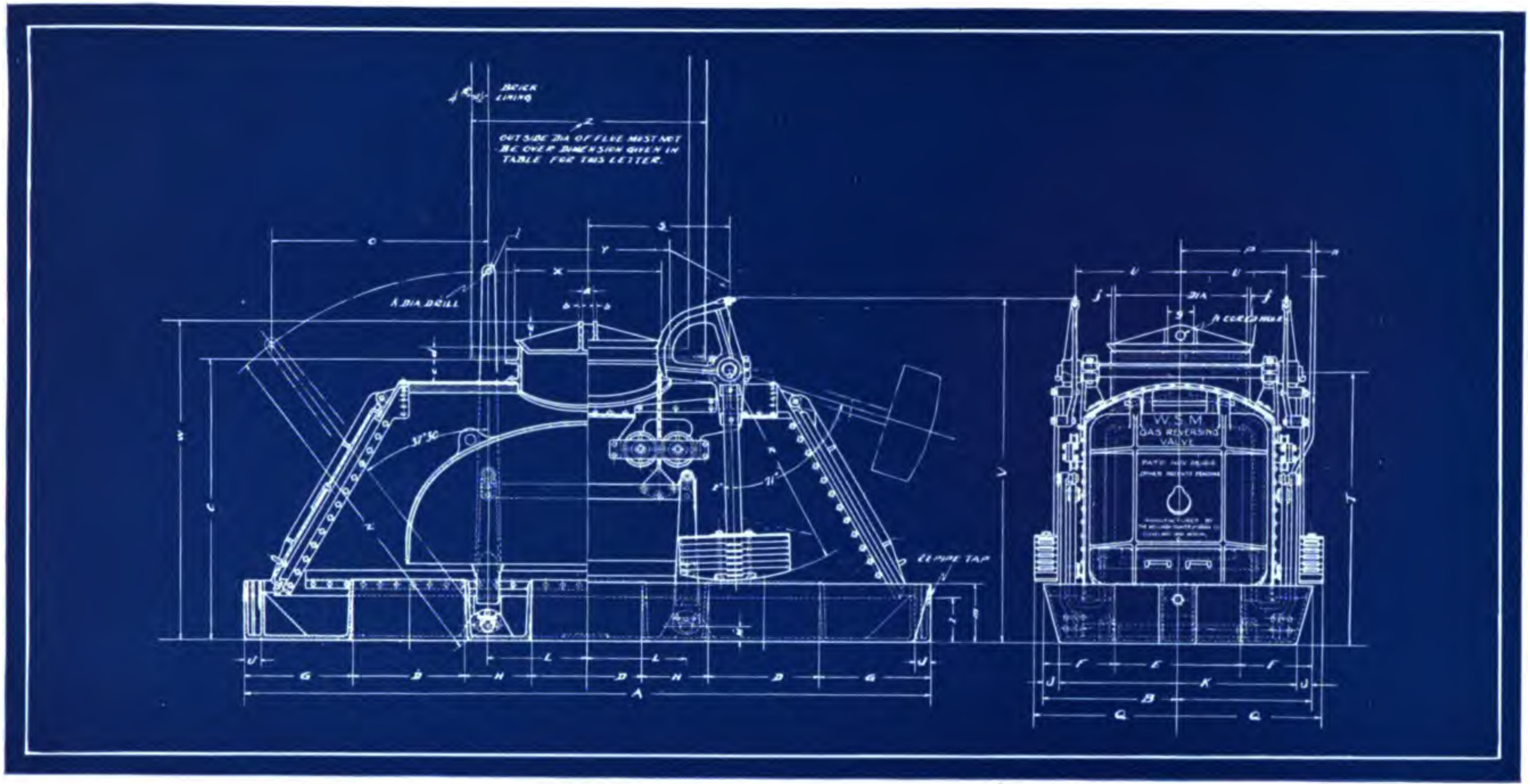


Figure 116—THE W-S-M REVERSING VALVE


BRICK LINING
OUTSIDE DIA OF FLUE MUST NOT BE OVER DIMENSION GIVEN IN TABLE FOR THIS LETTER.
A DIA DRILL
1½ PIPE TAP
W.S.M. GAS REVERSING VALVE
A B C D E F G H J K L N O P Q R S T U V W X Y Z

DIA. SIZE OF VALVE	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	a	b	c	d	e	f	g	h	i	k	l	m	n
18	116	54	51¼	13	20	17	25	13½	4	46	16	2¾	60	36½	27½	27¼	36½	17¼	49¾	20¼	64¼	57⅝	21	25	37½	2	½	6	3	2	½	4	1⅝	1	1 1/16	8¼	12¼	¾
21	116	61	52¼	13	27	17	25	13½	4	53	16	2¾	60	36½	31	30¾	36½	17¼	49¾	23¾	64¼	58⅝	24	28	42	2	½	6	3	2	½	4	1⅝	1	1 1/16	8¼	12¼	¾
24	131	60	58	18	25	17½	25	13½	4¼	51½	18	3	64	39	28½	30½	42¾	25½	56½	22¾	72½	65⅜	27½	31½	46½	2¼	¾	6	3	2½	⅝	4¾	1⅞	1	1 1/16	9¼	13¼	¾
27	131	67	59⅜	18	32	17½	25	13½	4¼	58½	18	3	64	39	32	34	42¾	25½	56½	26¼	72½	66¾	30½	34½	51	2¼	¾	6	3	2½	⅝	4¾	1⅞	1	1 1/16	9¼	13¼	¾
30	131	74	60¾	18	39	17½	25	13½	4¼	65½	18	3	64	39	35½	37½	42¾	25½	56½	29¾	72½	68⅛	33½	37½	55	2¼	¾	6	3	2½	¾	4¾	1⅞	1	1 1/16	9¼	13¼	¾
36	186	73	76	30	34	19½	30	18	4½	64	27	4	96	58½	35	39	57	38	74	28½	93½	86¾	40	44½	63½	3	1	6	3½	3	¾	7	2¾	1¾	1 9/16	12	16	1
42	186	85	76½	30	46	19½	30	18	4½	76	27	4	96	58½	41	45	57	38	74	34½	93½	87¼	46	50½	72	3	1	6	3½	3	¾	7	2¾	1¾	1 9/16	12	16	1
48	200	92	85½	36	50	21	28	18	4½	83	31½	4¼	96	58½	43½	48½	64¼	42½	82	36¾	103½	96¼	52	57	80½	3	1	6	3½	3	⅞	7	2¾	2	1 9/16	13	17	1¼

Figure 117—W-S-M REVERSING VALVE DIMENSIONS

ney. Waste gases from the furnace flow from whichever outside port the hood is covering to the chimney port. This leaves a clear passage for the fuel gas or the air entering the casing through the mushroom valve at the top to pass through the third port to the furnace or regenerator. Reversal of the flow of gas or air is accomplished by moving the hood to a position over the center port and the one previously uncovered.

The base of the valve is a cast iron rectangular pan with three walled openings or ports.

The hood which covers the center and one end port is semi-elliptical in vertical cross section and vertical sides. It is made of a rigid unyielding open hearth steel casting.

The base pan holds a quantity of water so that when the hood is over the ports a water-seal is formed to prevent the escape of gas. The base pan has a tapped hole at each end for a water pipe. There is a perforated strainer at the intake end and a dam plate at the outer end to hold the water at such a level as to allow the hood to extend three inches into the water forming the seal.

The outer casing is made of steel plate and should be lined with fire-brick, if producer gas is used. It has cast iron door frames and door at each end through which the hood may be removed or inserted. Each door has a small peek hole with a swinging cover which enables inspection at any time.

On the top of the casing is a cast iron neck which connects either with the fuel gas flue or the air intake, depending upon the purpose for which the valve is used.

The hood is moved by a series of levers and coupling shafts which extend through the water under the casing and into sockets on the hood. The shafts move on chilled iron bearings. The operating mechanism is actuated by a lever shown on page 257.

With all hand operated valves, a special stand is furnished, also eight sheaves with hangers, clamps and 120 feet of wire rope. The diagram below shows the connections for the operating mechanism.

At each side of the valve is a counterweight attached to an arm and sector over which passes a chain connecting with the supports of the hood. The form of this sec-

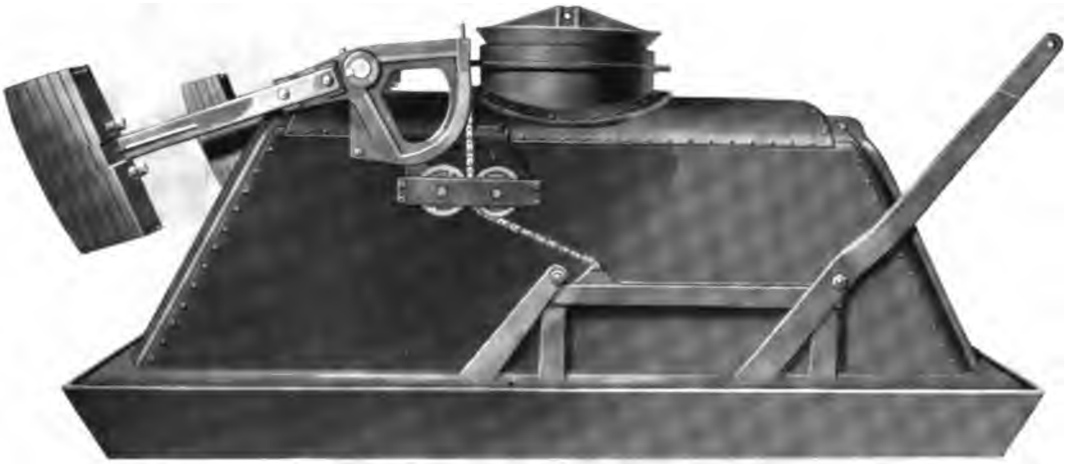


Figure 118—THE W-S-M REVERSING VALVE

This view shows the simplicity of the reversing mechanism. The long lever is actuated by a wire cable from a winch on the charging floor.

tor is such that the counterweights balance the weight of the hood at any position.

Features of the W-S-M Valve

The valve has the following distinct advantages, the combination of which will be found in no other valve used for reversing the gases of melting or heating furnaces.

Freedom of Flow: The semi-elliptical form of the hood allows free flow of the gas, as there are no abrupt turns or constricted areas in the passage formed by the ports and hood. This feature is very important in obtaining maximum efficiency from the stack draft.

No Gas Leakage: All leakage or waste of gas is prevented by the water-seal. Such a seal does away with all packing, tightening and adjusting, the only attention required being the flow of a small quantity of water into the bed plate to replace the amount evaporated.

Compactness: Due to its compactness, the valve requires comparatively little floor space and adapts itself to various arrangements of flues from the regenerators to the stack.

Ease of Operation: The weight of the hood is counterbalanced by the weights on the lever arm, balancing the hood at any position. To move the hood it is only necessary to exert enough force to overcome friction. This is an important feature in hand operated valves.

Durability: The materials used for each part of the valve are selected to give long life. The casing is lined with firebrick and all working joints are protected from the hot gas. Bearings and wearing parts are designed with a high factor of safety. There are chilled bearings in the bed plate for the rocker arms and hardened links and pins on the hood supporting arms.

Accessibility for Inspection: The construction of the valve is such that all parts may be easily inspected and removed. The doors at each end of the outer casing are large enough to allow the hood to be removed. The reversing mechanism does not require the removal of bolts or nuts in placing or removing. The levers, links and pins of the operating mechanism are on the outside, permitting oiling and adjustment and insuring long life and easy operation.

The general dimensions of the various sizes in which this valve is manufactured are shown in the table on page 254

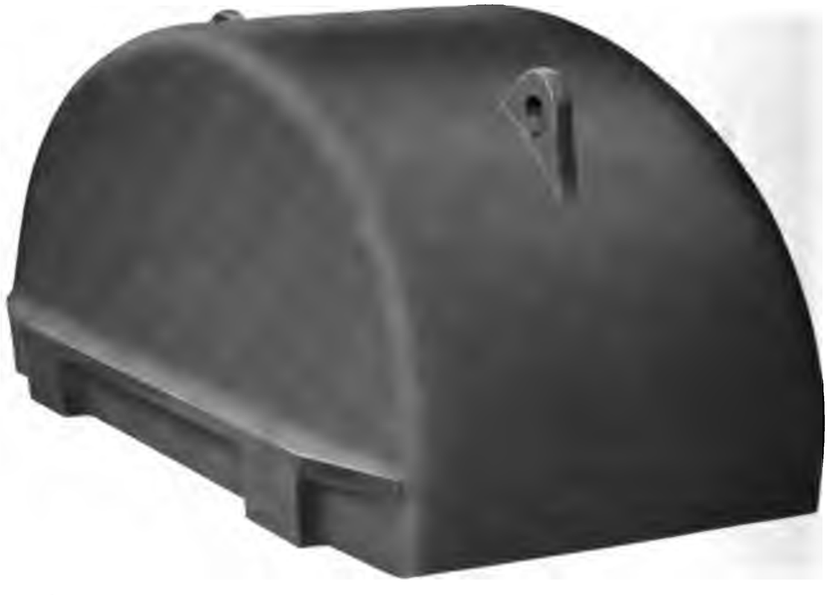


Figure 119—Cast Steel Hood for the W-S-M Reversing Valve

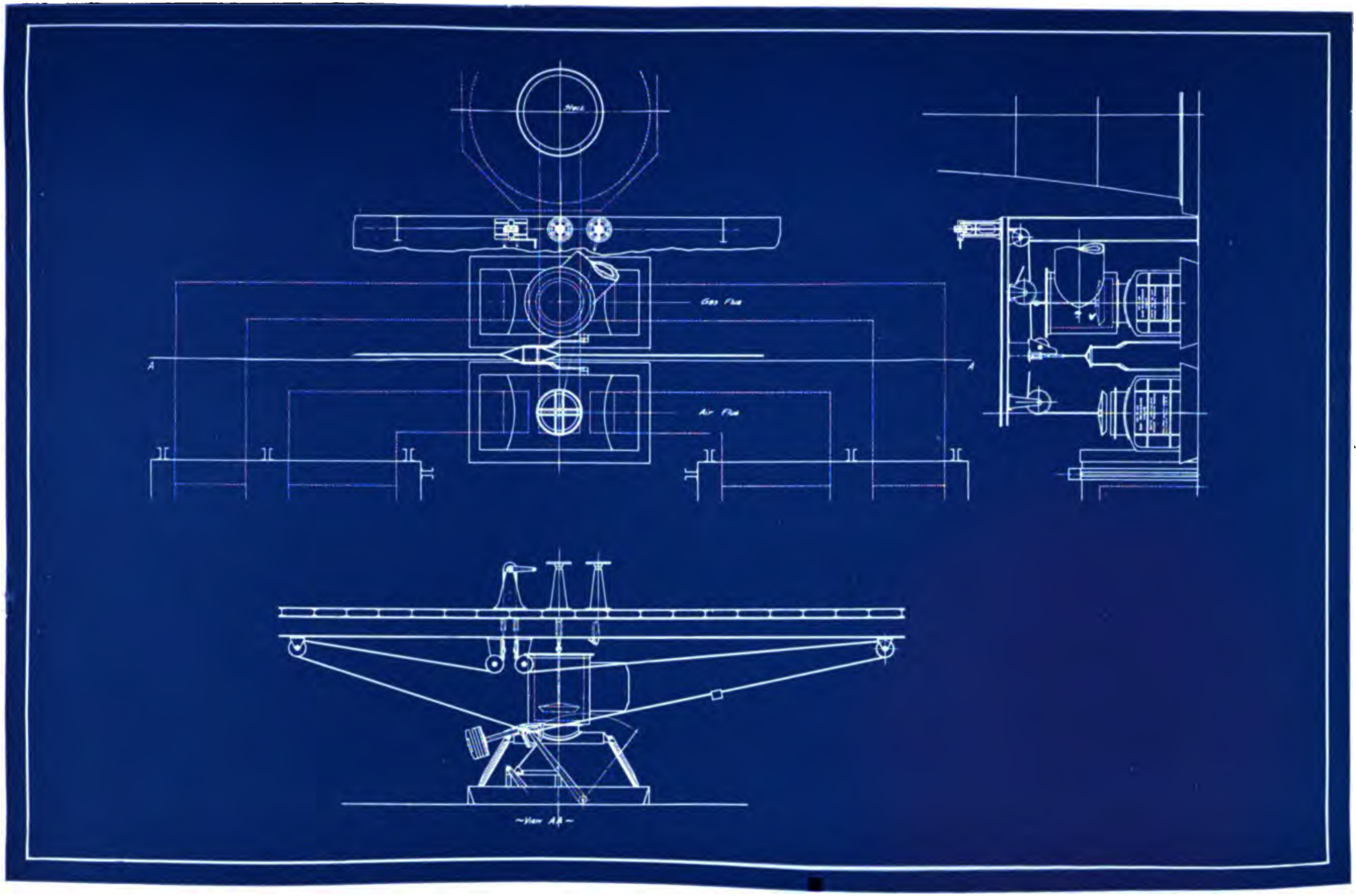


Figure 120—MANNER OF CONTROL OF GAS AND AIR REVERSING VALVE of a furnace using regenerators, whereby a reversal of both valves is made simultaneously from the one operating winch on the charging floor.

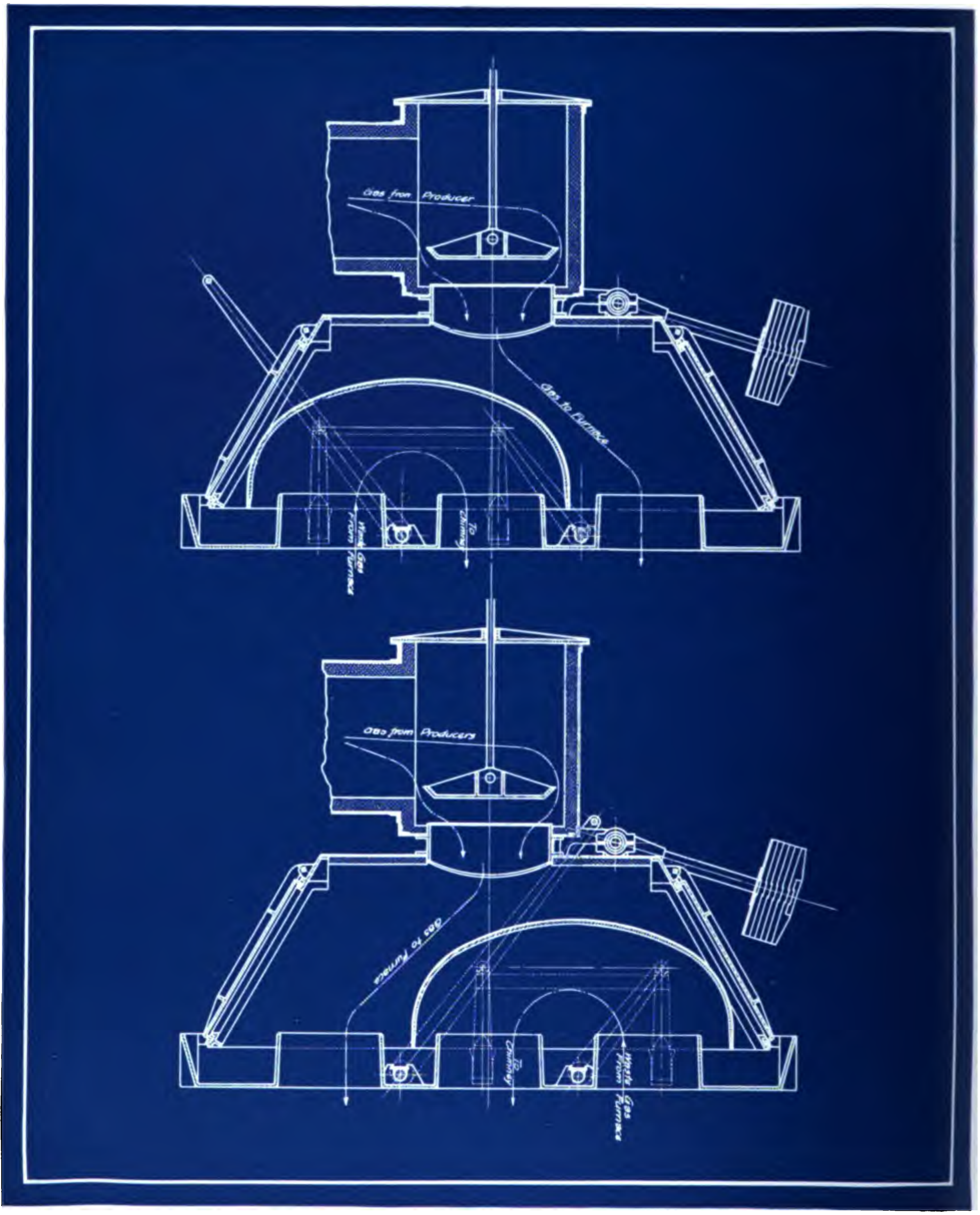


Figure 121—DIAGRAM SHOWING THE DIRECTION OF FLOW OF THE GAS

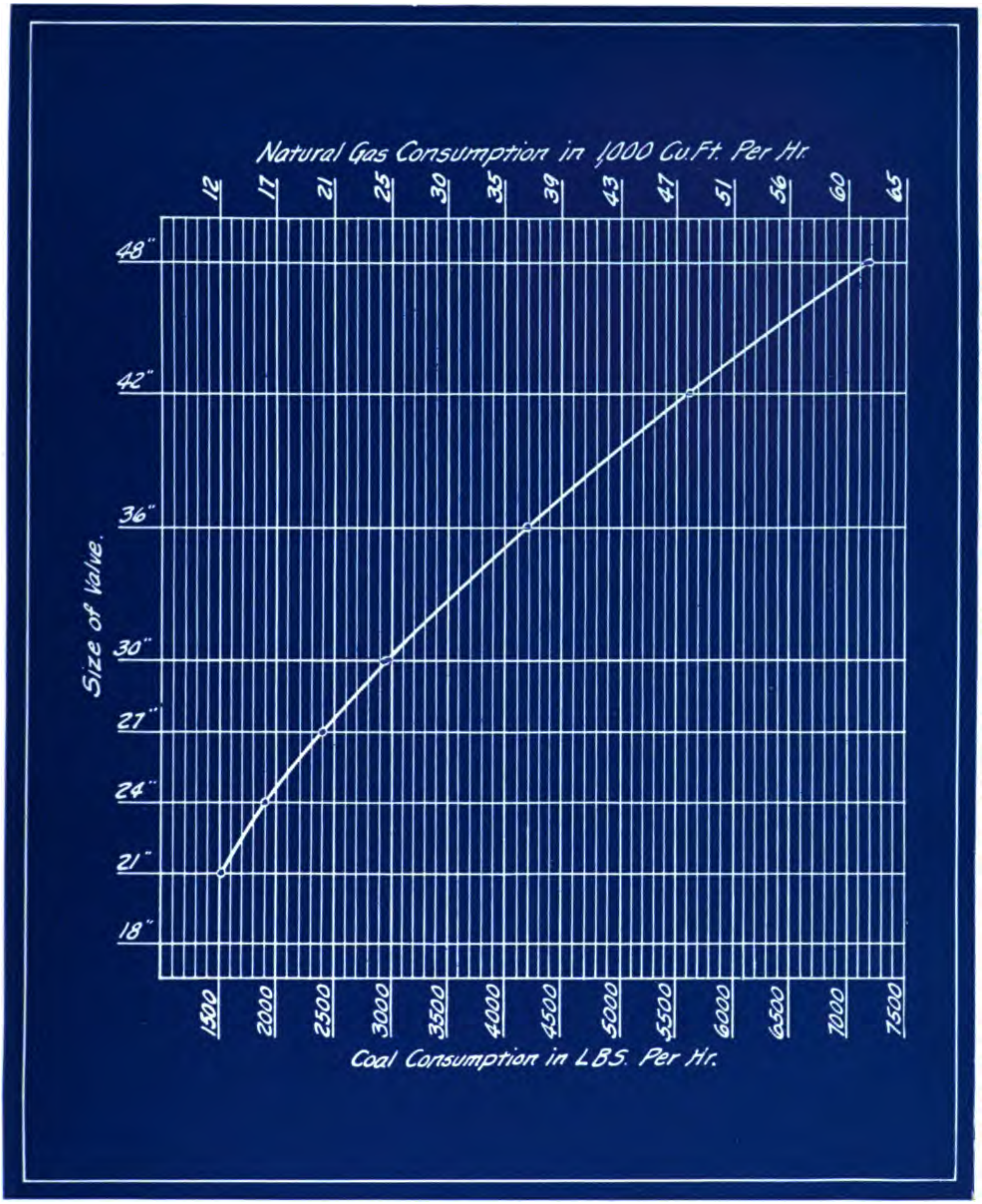


Figure 122—CURVE FOR DETERMINING SIZE OF GAS REVERSING VALVE

To be used when either the coal consumption in pounds per hour or the natural gas consumption in 1000 cubic feet per hour is known.

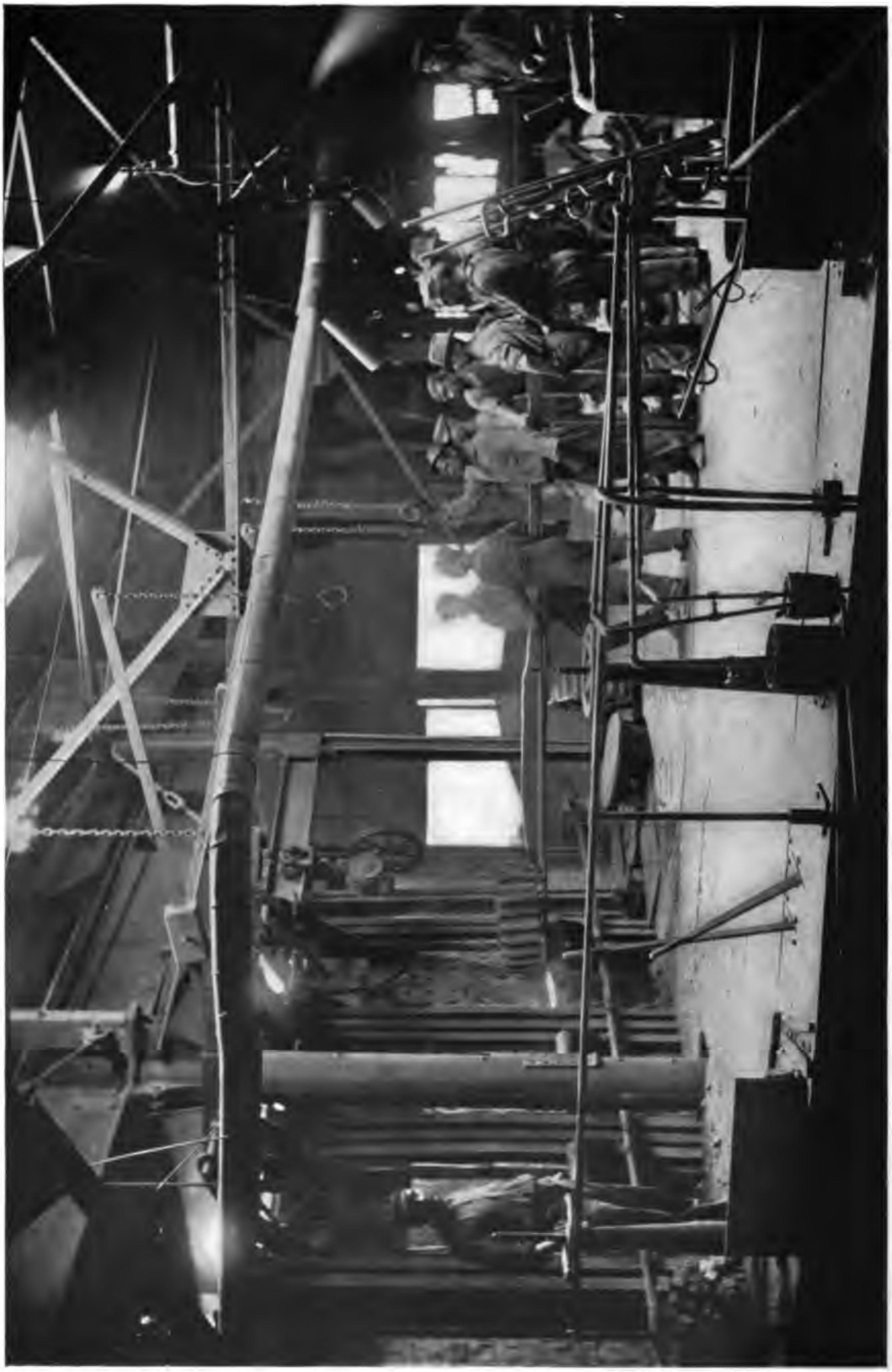


Figure 123—CHARGING AN OPEN HEARTH FURNACE BY HAND

Before the invention of the Wellman charging machine. This work with a large gang of men even for a small furnace was laborious, time consuming and in hot weather exhausting to the men.

CHAPTER XXII

Charging Machines and Appurtenances

The quantities of the raw materials to be charged into the furnace are so great, except for very small installations, that manual charging is out of the question. Mechanical chargers do the work with precision and speed.

Less than twenty-five years ago, charging of open hearth steel furnaces was done by hand, as illustrated on page 260.

Hand charging inefficient: With the best of team work a considerable loss in time during the charging process was inevitable, and the furnaces were cooled from the long-opened doors. The inability of the men to handle heavy pieces and the labor troubles incident to working the men on hot floors in summer weather augmented the excessive cost already made necessary by the use of large charging crews. This cost proved to be a strong deterrent influence against the expansion of the steel indutry at a time when railway and industrial growth was making strong demands on steel production.

Pioneer Charging Builders: Mechanical chargers were thus made necessary. The Wellman-Seaver-Morgan Company originated, first built, developed, and for many years was the sole constructor of such machines for open hearth furnace work. Charging boxes and cars came as a matter of course.

Now generally used: Now a machine is considered a necessity; there is no steel plant of size in the country that is not equipped with chargers. And there are few steel companies in America, few, indeed, in the world, who are not users of Wellman equipment. To its use is directly traceable a very large proportion of the economies secured in the modern manufacture of steel.

Several types: Different conditions have called forth three different types of open hearth chargers: the high type floor, the low type floor, the crane type. Many special machines of various kinds have also been built for charging heating furnaces, for handling and rehandling slabs, ingots, blooms, billets, wheels, tires, etc. Special machines may be built for either open hearth or heating furnaces and for manipulating purposes, even where the space may be thought too constricted.

All steel construction: All W-S-M charging machines and manipulators are all steel and conform in every respect to the most modern engineering practice. They are provided with the latest devices for the protection of workmen, are simply and durably built, and readily accessible for inspection and repair.

The First Four Machines Saved $4,761,850 in 22 Years

One of the first four open hearth charging machines built is pictured above, after twenty-two years of constant service.

These marked the beginning of a new era in American steel manufacture. They are interesting, not merely, as historical relics; they are today live and tangible assets of the Homestead Steel Works, where they were installed in 1895 by S. T. and C. H.

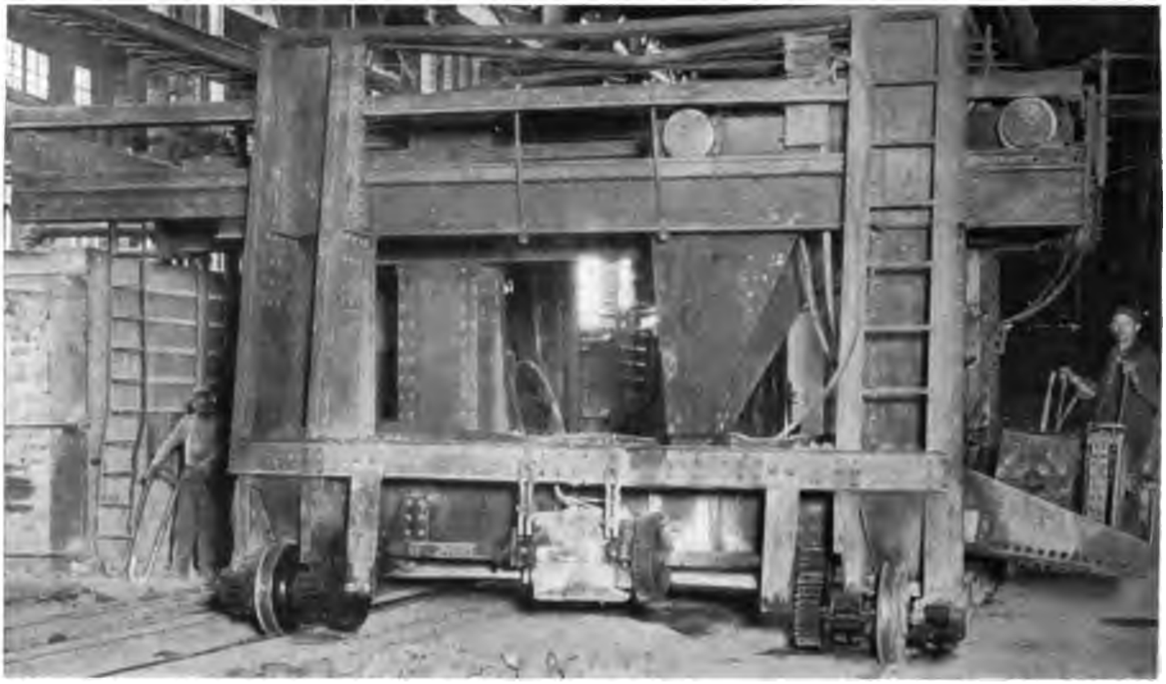


Figure 124—FIRST TYPE OF HIGH CHARGING MACHINE

Wellman. Since the date of their installation these four Wellman high type open hearth charging machines have charged into the Homestead furnaces 9,523,700 tons of pig iron and scrap steel.

After these machines had been running for several years Mr. Charles M. Schwab, writing to Mr. S. T. Wellman, gave the amount of direct and indirect savings to his company from their use as fifty cents per ton. (This saving was on labor charges—years ago). Figured on this basis the total saving due to these machines was $4,761,850.

England, Scotland, Wales, Russia, Belgium, France, Germany, Sweden, Spain, India, China, Japan, Mexico, and Canada have not been slow to follow the United States in making demand for these labor-reducing factors.

The filled charging boxes are picked up by the charging machine and thrust into the furnace through the charging door openings. The ram by which they are held is revolved, dumping the load from the box. On account of the severe duty to which the charging machine is put all castings are of open hearth steel, no cast iron being used.

In selecting a machine, the choice is made on duly weighing the advantages of the several types and as guided by the following conditions.

High Type Floor Charging Machine

A high type floor machine has been found preferable where the floor space is limited. While machines are built to suit any clearances within reason, it is always to the interest of the customer to use standard clearances wherever practical.

The machine illustrated is built to handle loads varying from 5000 to 12000 pounds, and is furnished with any standard type of motors and control equipment desired.

Low Type Floor Charging Machine

Where floor space is more plentiful and particularly where it is desirable to operate a ladle crane over the charging machine, the low type is recommended. It is built in capacities ranging from 7000 to 15000 pounds. It may be built for any reasonable capacity and to suit special conditions as desired. Any electrical equipment can be used and rotating trolleys or carriages may be supplied if conditions require.

Crane Type Charging Machine

The crane type charging machine is used extensively abroad. It is built with a rotating trolley if required and furnished with or without auxiliary lifting trolley. Any reasonable clearance space can be accommodated and electrical equipment supplied. For simplicity and for usual American practice either of the two foregoing types is recommended in preference to this one.

Long Stroke Open Hearth Charging Machine

This is a special machine built for use with the duplex system of melting, using two charging tracks between the machine and the furnaces. The particular machine pictured above has a stroke of 30 feet and is built along the lines of a standard high type floor charger.

In the design of the Wellman charging machines the following conditions and limitations have influenced the proportions adopted:

The selection of the type of machine, whether high, low, or crane type depends upon the floor space and its uses.

The span from rail to rail on the floor should not be such as to require excessively heavy carrying girders to give the necessary rigidity.

The height must be such as not to require too great width to secure stability against overturning.

The width must be such as to prevent a cramping or twisting tendency of the machine in traveling, and at the same time not take up any more floor space than is necessary.

The main traverse and lifting motion must travel smoothly, with little friction, starting and stopping under perfect control of the operator; otherwise stock from carelessly filled charging boxes may be spilled.

The charging bar or ram must be under instant control, should revolve either in right or left hand direction, be heavy enough to stand hard rough usage and work with ease.

The electrical equipment must be accessible, its capacity for. overloads ample and thoroughly provided with cutouts, circuit breakers and other necessary devices against injury.

The lubrication must be thorough and capable of easy renewal of greases and oils and inspection.

It is advantageous to have on the charging floor in front of a furnace for immediate use small stocks of patching refractories, ore, fluorspar, etc. A machine should have enough clearance from the floor to permit of this practice. The crane type of machine permits this without limit while the other types of machine admit of somewhat smaller piles being so placed.

Figure 126 shows a Wellman electrically operated high type charging machine at the plant of the Sizer Forge Company, Buffalo, New York. It charges electric furnaces and handles a charging box weighing with its contents 5000 pounds. It exerts a draw bar pull of 5000 pounds at the end of the ram when shifting charging cars. The general dimensions of this machine are given on the blue print on page 267.

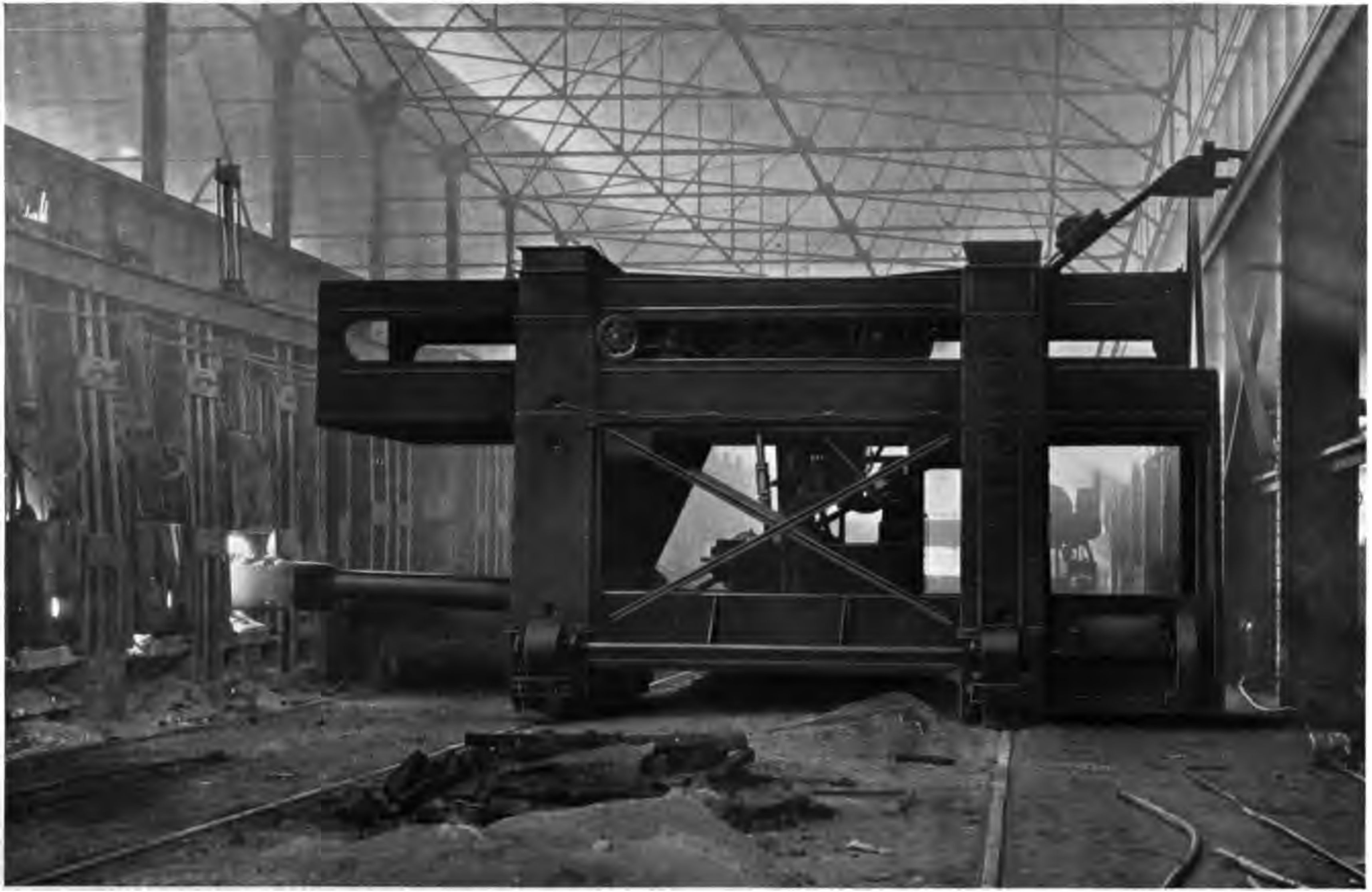
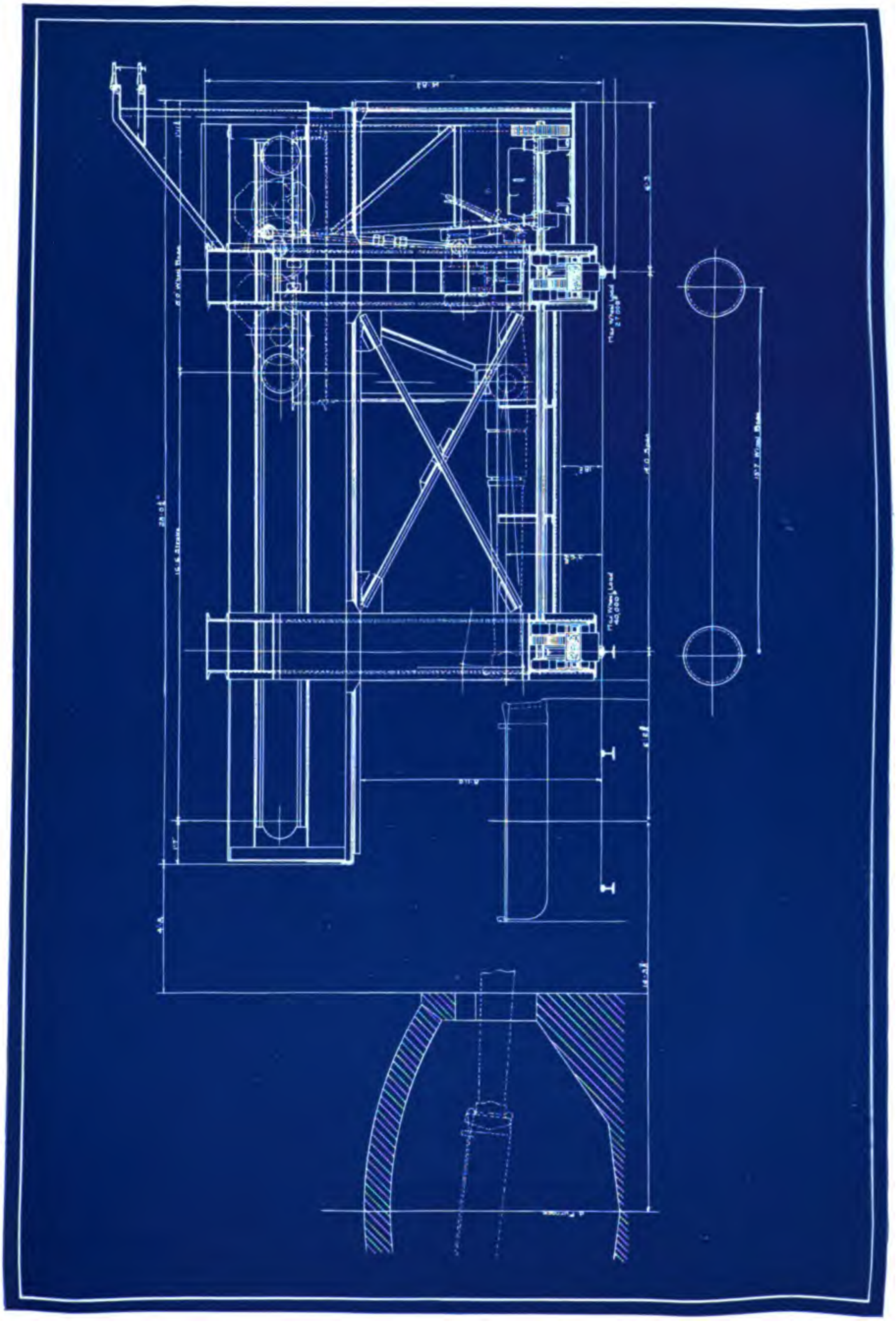


Figure 125—W-S-M HIGH TYPE CHARGING MACHINE

This photograph shows a 10,000 pound capacity high type charging machine at the plant of The Upson Nut Co., Cleveland, Ohio. The first four W-S-M high type charging machines for open hearth furnaces were installed in



1895 at the Homestead Steel Works and are still in daily service. After these machines had been running several years, Mr. Charles M. Schwab, in a letter to Mr. S. T. Wellman gave the saving of these machines to his company as fifty cents a ton and that saving was on the basis of labor charges twenty years ago.

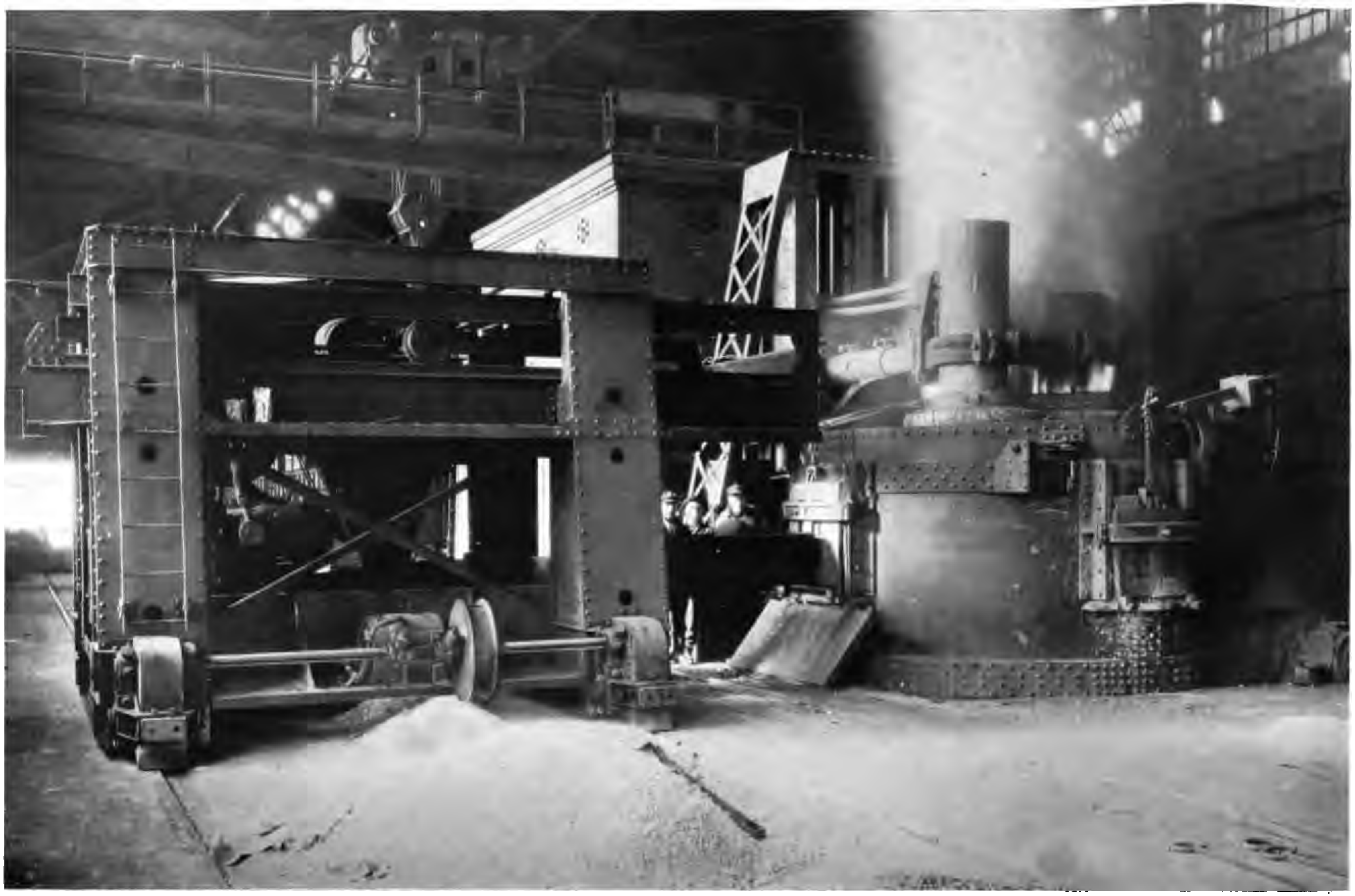
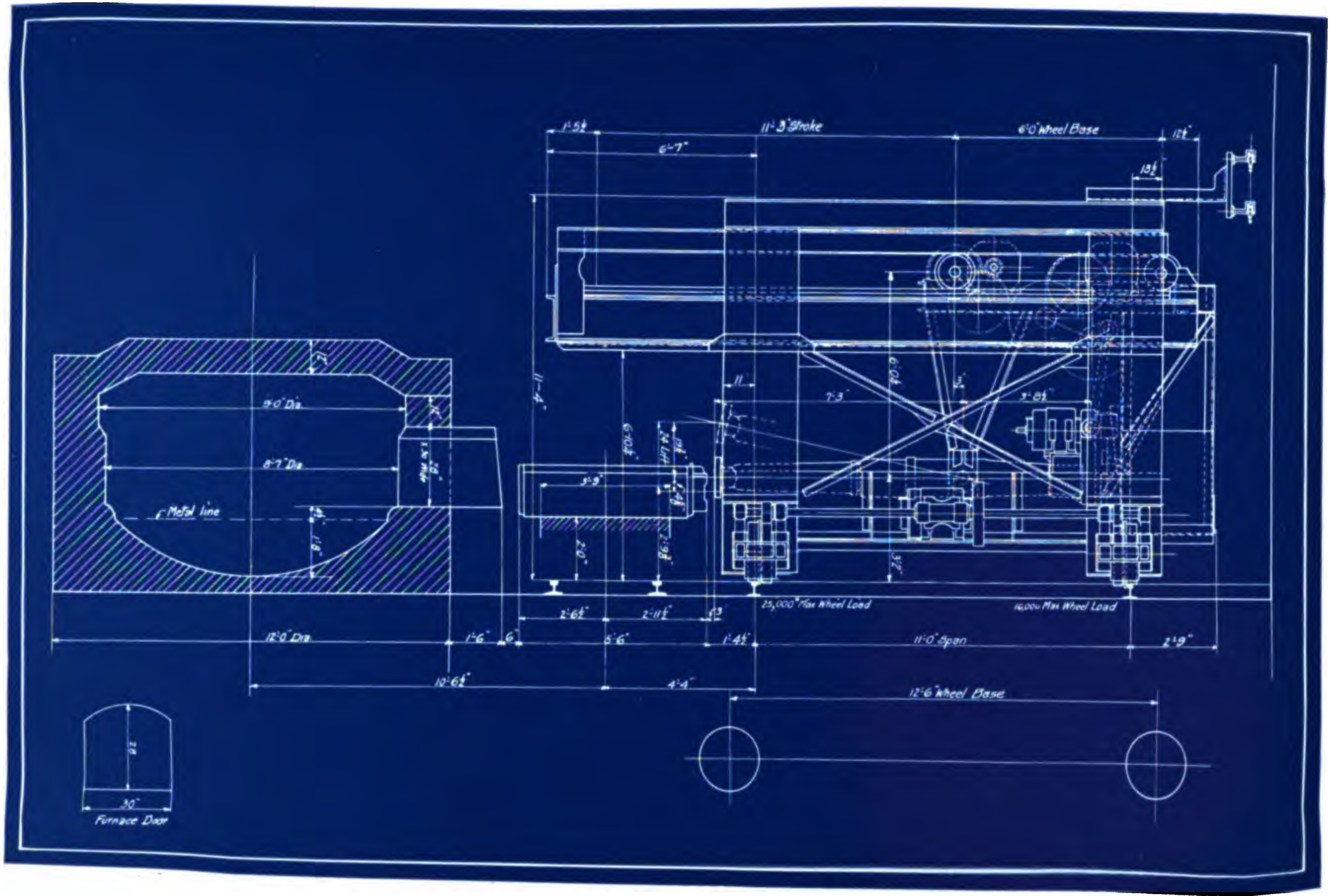


Figure 126—W-S-M CHARGING MACHINE AT AN ELECTRIC FURNACE

This photograph shows a W-S-M electrically operated high type charging machine working at the plant of the Sizer Forge Company, Buffalo, New York. This machine is used to charge electric furnaces and is capable of hand-



ling a charging box weighing with its contents 5,000 pounds. It can also exert a draw bar pull of 5,000 pounds at the end of the ram when shifting charging cars. All W-S-M charging machines are provided with the latest devices for the protection of the workmen. They are simply and durably built and are readily accessible for repair.

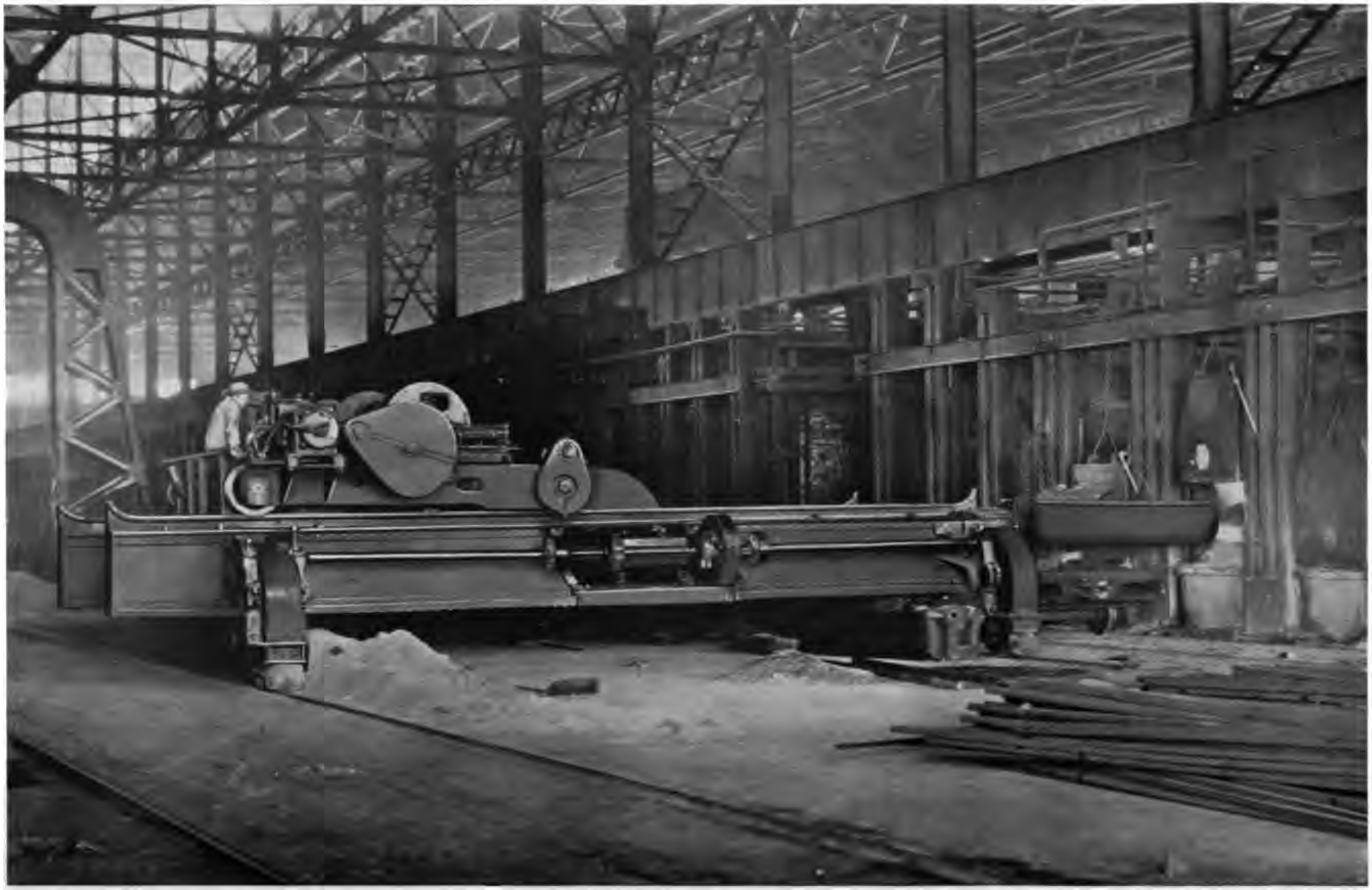
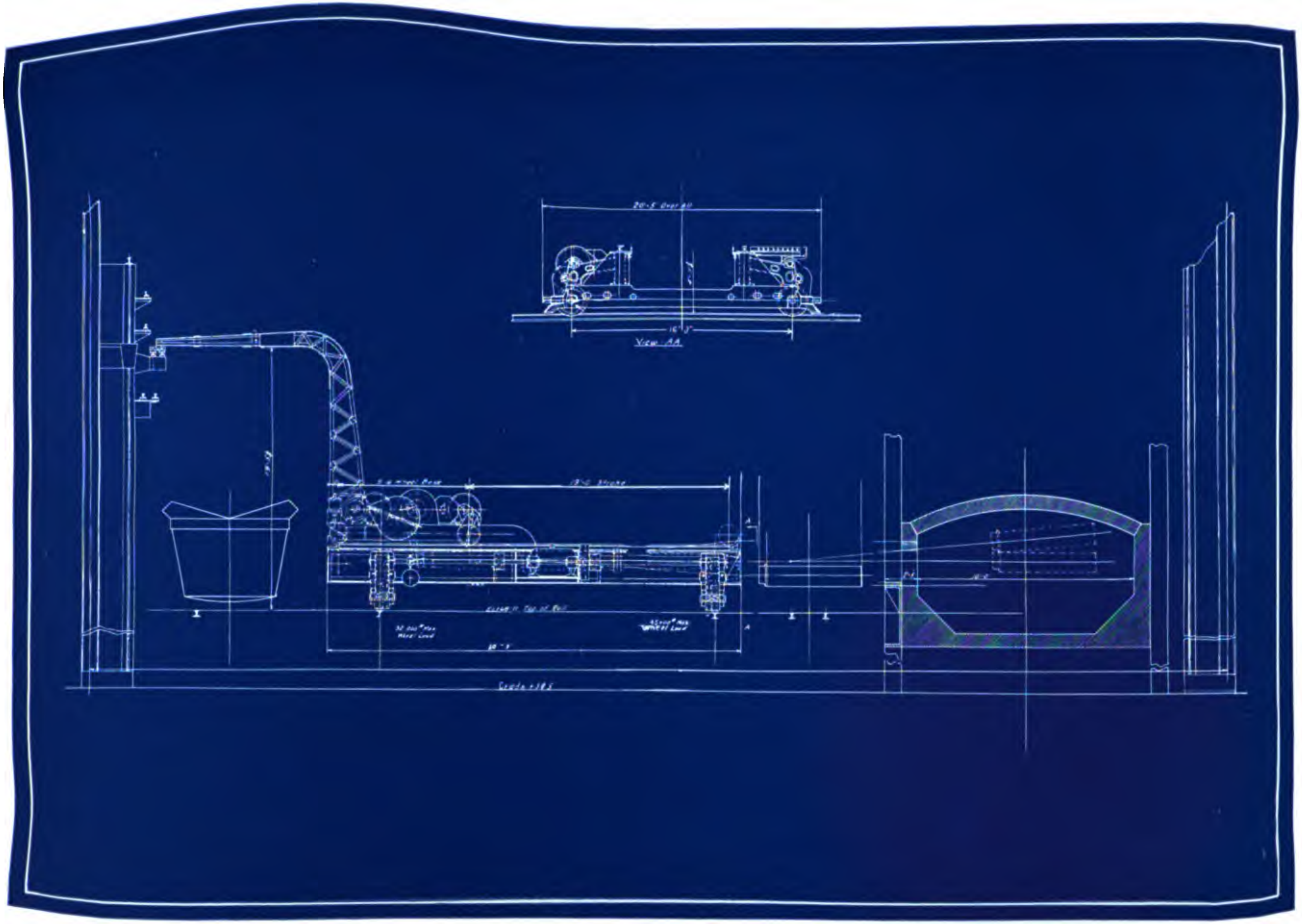


Figure 127—W-S-M LOW TYPE CHARGING MACHINE

Where floor space is more plentiful and particularly where a hot metal ladle crane is operated over the charging machine, the low type is desirable. This is a standard type built in capacities ranging from 7,000 to 10,000 pounds.



W-S-M charging machines are built entirely of steel and conform in every respect to the most modern engineering practice. They are provided with the latest safety devices. The 10,000 pound machine shown in the photograph is one of two similar machines installed at The Trumbull Steel Co., Warren, Ohio.

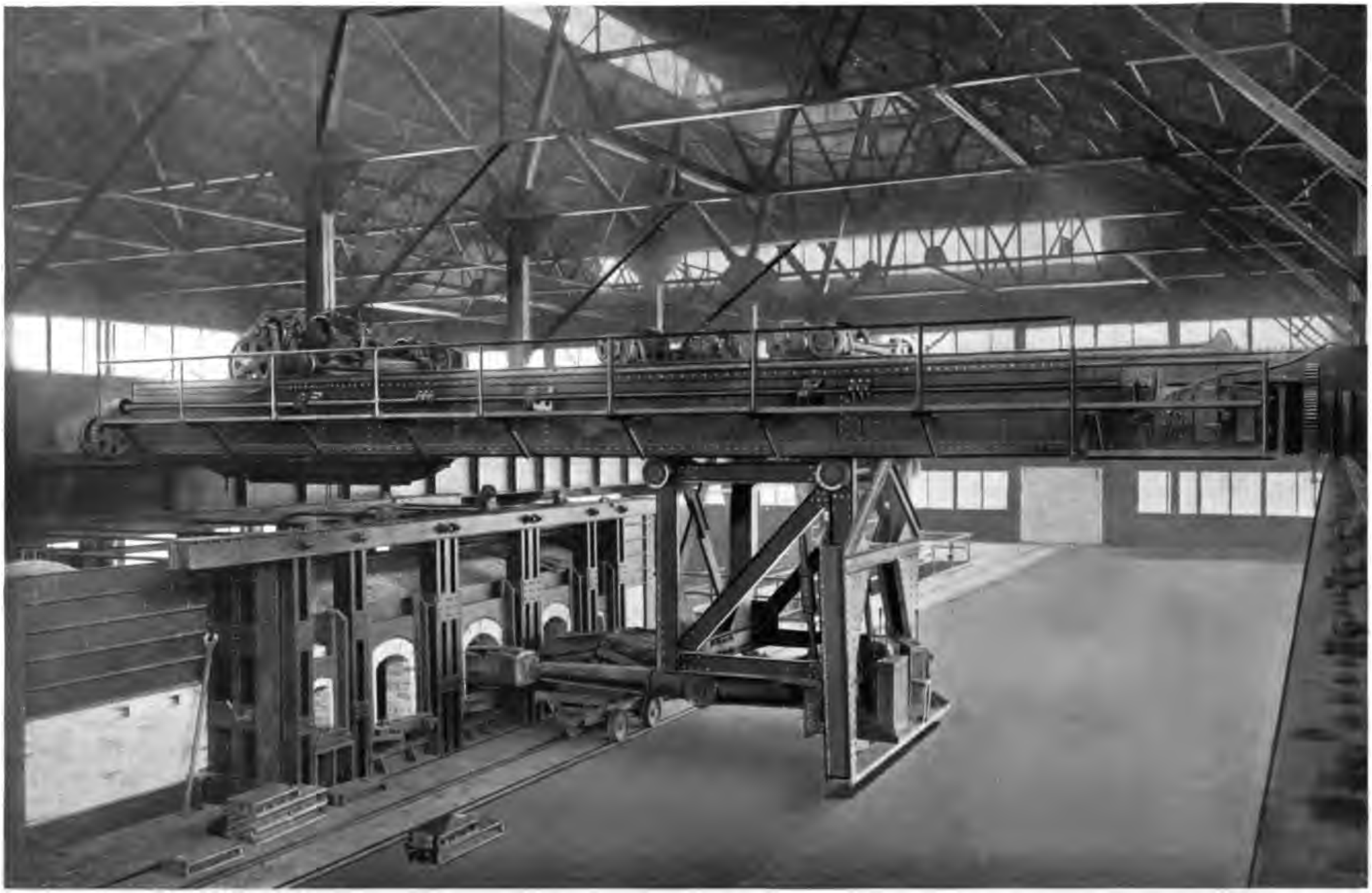
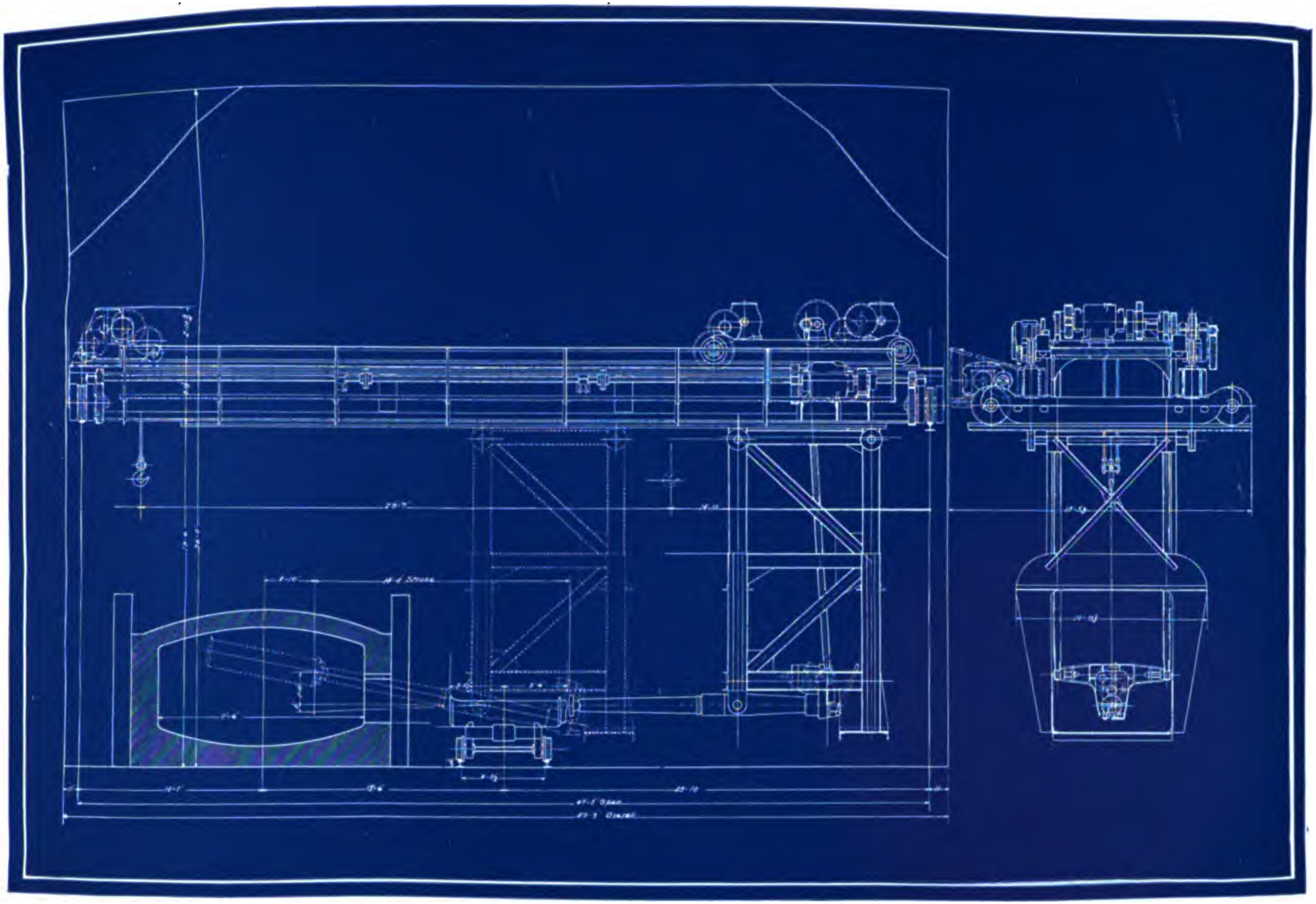
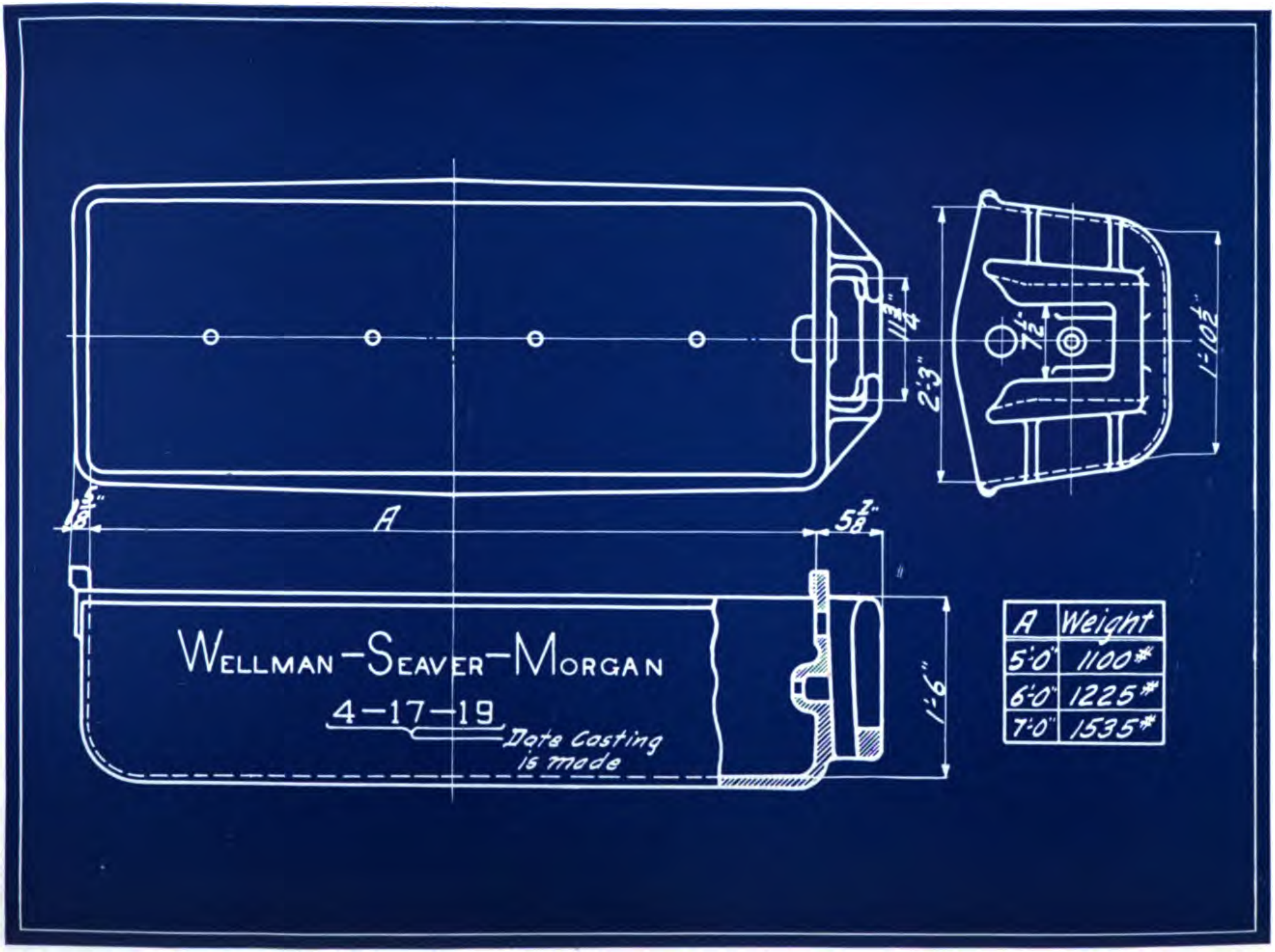


Figure 128—W-S-M CRANE TYPE CHARGING MACHINE

This photograph shows the installation of a crane type open hearth charging machine at the Latrobe, Pa., works of The Railway Steel Spring Co. This machine has a 15-ton crane trolley. This type of machine is used extensively



abroad. In fact W-S-M charging machines are found in operation in England, Scotland, Wales, Russia, Belgium, France, Germany, Sweden, Spain, India, China, Japan, Mexico, Canada, and throughout the United States.



A	Weight
5'-0"	1100#
6'-0"	1225#
7'-0"	1535#

Figure 129—WELLMAN CAST STEEL CHARGING BOXES

Wellman
Cast Steel Charging Box Cars

Both cast steel and steel plate boxes are used. Until recently few of the former were to be seen, but the preference today is for cast steel boxes. They are doubtless far superior in rigidity and heat endurance, which means a longer life. Sizes have been rather well standardized, the width and height being as shown by blue print on page 272, while the usual lengths (A) are 6,7, and 8 feet. Boxes of 4 and 5 feet lengths are often used on smaller furnaces.

Wellman
Cast Steel Charging Cars

The cast steel charging car illustrated on page 274 has met with great success.

The body is one piece steel casting well ribbed and spring mounted on axles carrying chilled iron wheels. These cars are built with MCB or Hyatt roller bearings and with either three-quarter size MCB couplers or drawheads and links. The extremely hard service to which charging cars are subjected limited the useful life of the old style structural car.

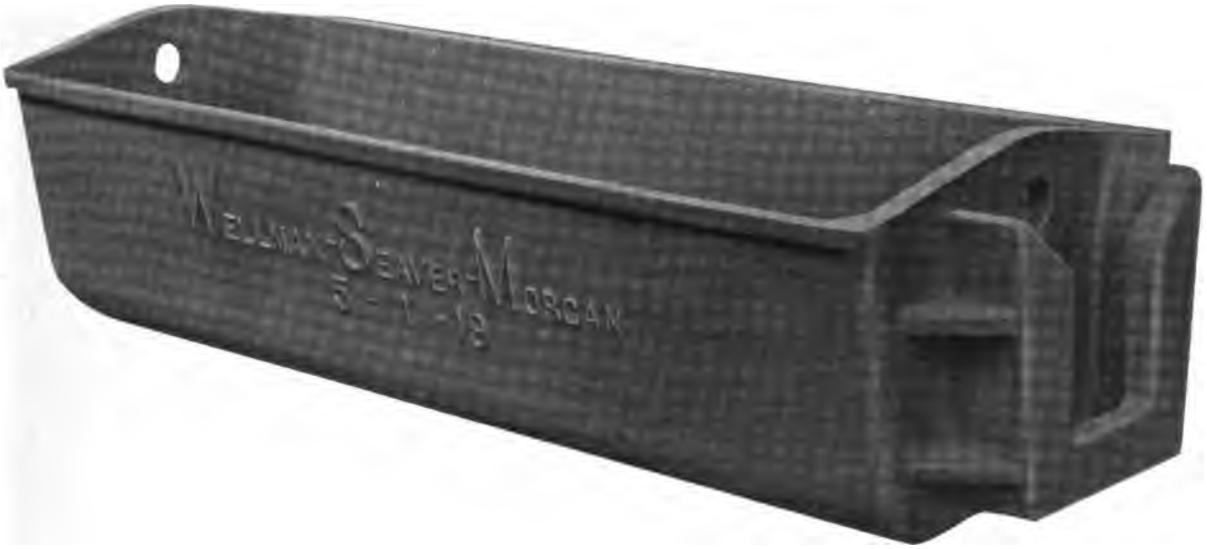


Figure 130—WELLMAN CAST STEEL CHARGING BOX

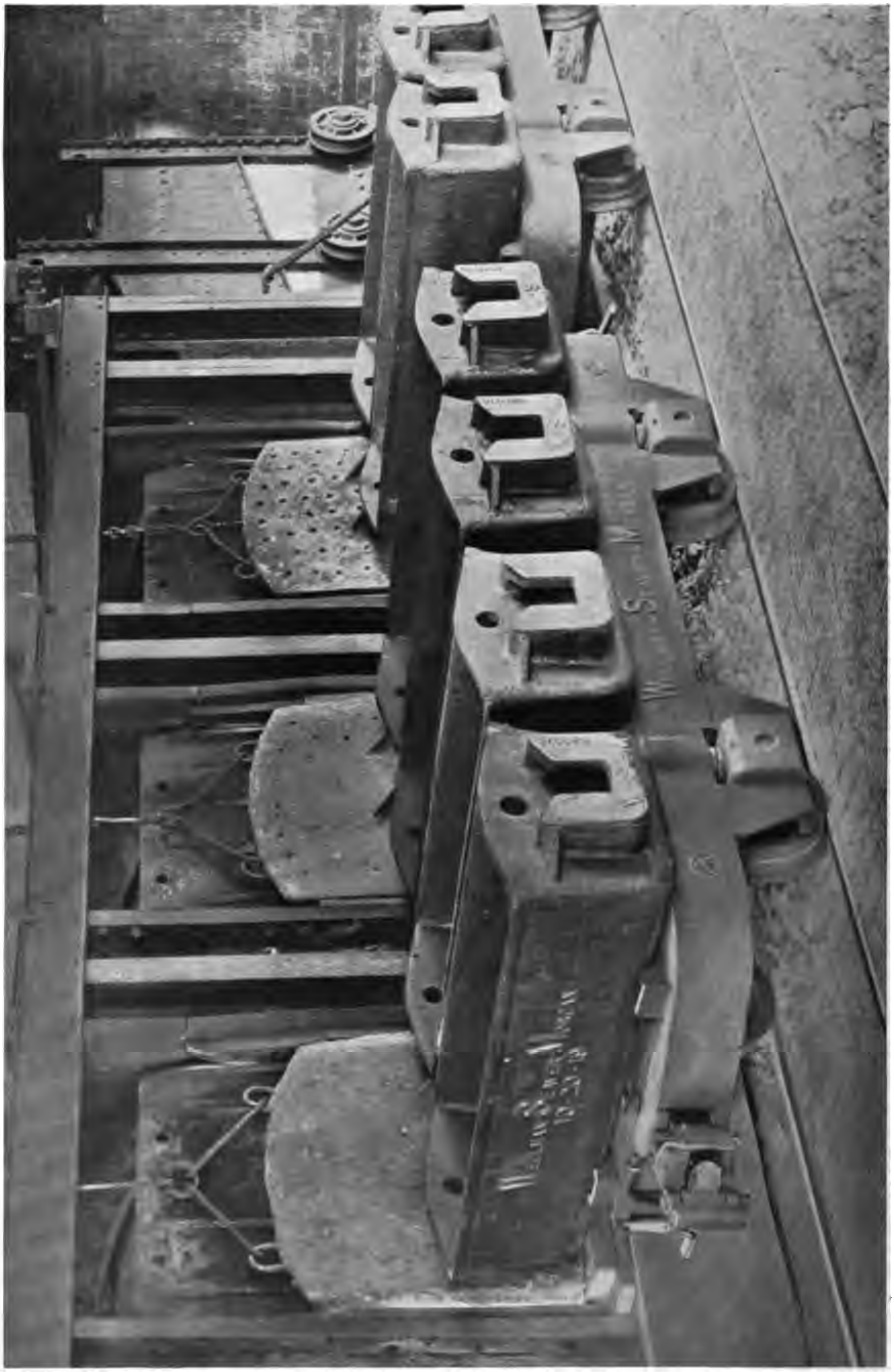
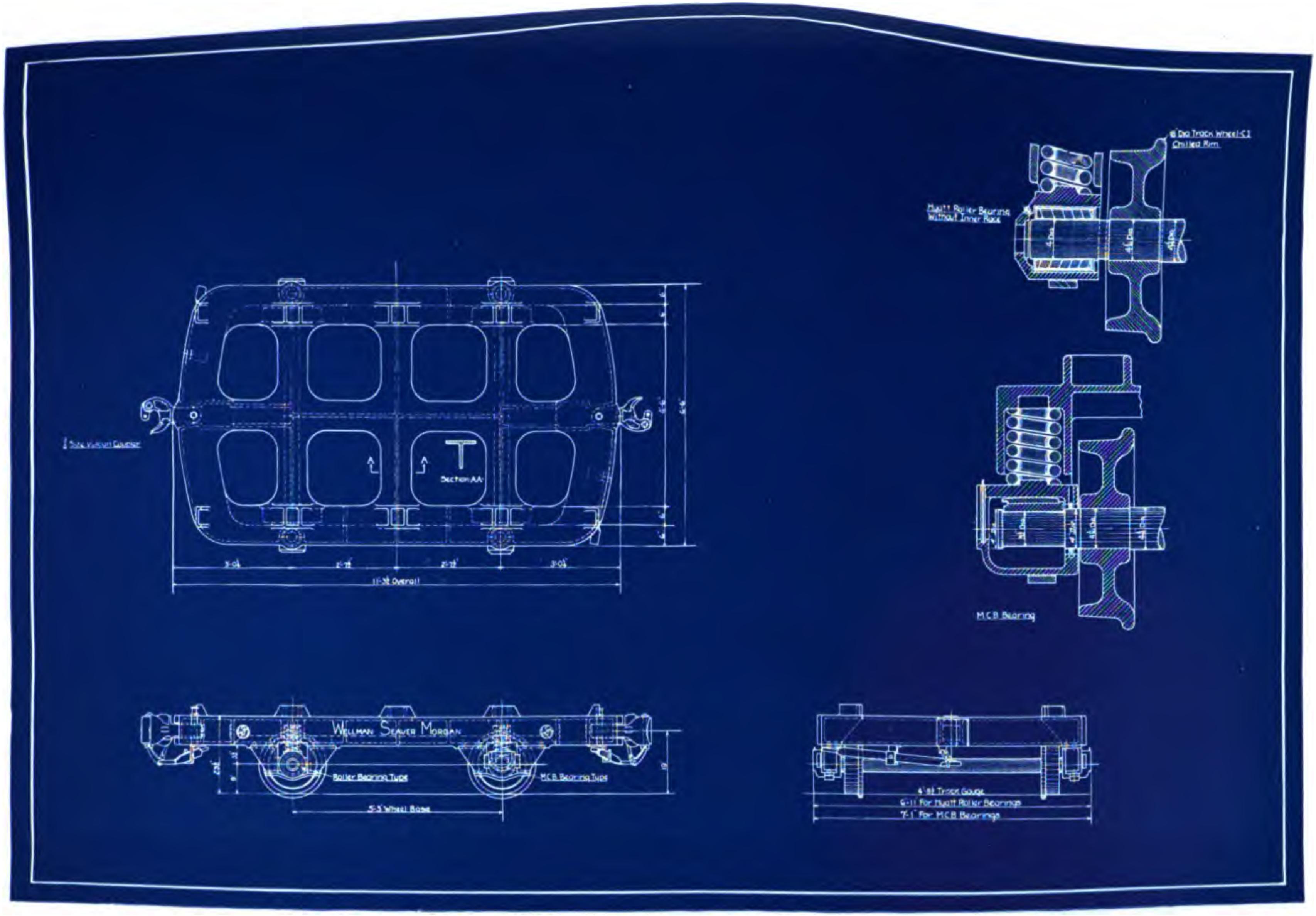


Figure 131—W-S-M CAST STEEL CHARGING CAR AND BOXES

This car carries charging boxes to open hearth furnaces. It is built of cast steel and equipped with automatic couplers. It has spring seats for the axle bearings. Either roller or plain axle bearings are supplied. The car will carry



four charging boxes. The boxes are made either of cast steel or of steel plate with cast heads. The all cast steel box is, however, superior in points of rigidity and heat endurance. Boxes are made in lengths varying from four feet to eight feet. The boxes are taken from the car and emptied into the furnace by charging machines.

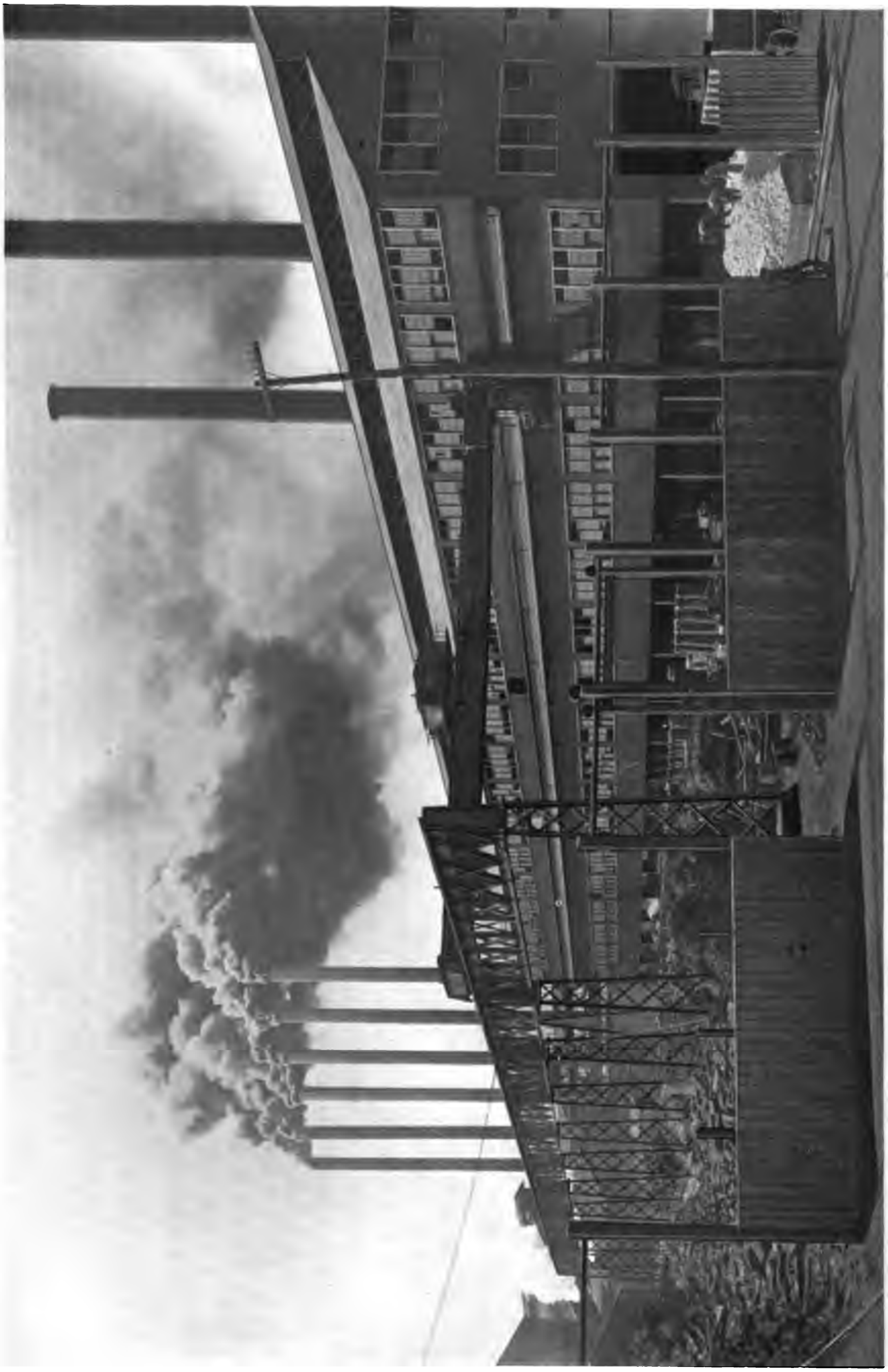


Figure 132—CRANE FOR STEEL MILL STOCK YARD

CHAPTER XXIII

Stock and the Stock Yard

Of the materials used in an open hearth furnace, all but the hot metal and fuel pass through the stock yard. Here, in accessible bins or sheds, properly classified and labeled, are stocked all of the charge materials, fluxes and refractories.

The high priced alloys and recarburizers should be stored in appropriate bins to avoid loss.

This part of the plant should be laid out for transfer from the inbound cars to the stock piles and thence to the furnaces with practically no manual labor. Ample track facilities must be provided for handling by locomotive cranes. The entire yard should be covered by either an overhead or gantry type electric traveling crane.

The tracks should be laid out to occupy a minimum of space, as the ground area is more valuable for storage piles than for more or less empty tracks. Frequent crossovers between parallel tracks should be so located as to enable cars standing for unloading at one bin to be conveniently bypassed for placing at another bin on the same track without disturbing the first car.

For economy of space, track curves should be as sharp as possible. For standard gauge tracks, a curve of 339′-0″ radius taking a standard No. 6 frog and for a 3′-0″ gauge a radius of 50′-0″ are practicable and found satisfactory in use. As far as possible, all frogs and switch points should be of the same number, length and planing. Alteration of the curve radius should be made beyond the heel of the frog.

Ground throw switch stands are preferable, as they are less liable to be the cause of injury to men walking along tracks, especially at night time. They should lie low and not have targets or lantern rods standing up, as many an injury has resulted from them.

Bin partitions should be made of reinforced concrete for economy of maintenance and of space. Flooring and runways of concrete will be found to be superior to wood for economy. A good substitute is a bed of from 9 inches to 22 inches of granulated blast furnace cinder, which, with moisture and a little time sets into a firm body.

For overhead traveling cranes a capacity of ten tons will be sufficient. If but one crane is in use, it should be rigged to substitute a charging box chain sling quickly for the usual magnet. Where two cranes are used, one should be equipped with each of these devices.

Locomotive cranes operating lifting magnets have a small engine and generator attached to the forward part of the turn-table near to the bearings of the boom.

A 36-inch magnet, the usual size, has a carrying capacity as follows:

Car wheels	6 wheels
Wrought iron scrap	900 lbs.
Pig iron	900 lbs.
Punchings	750 lbs.
Heavy plate scrap	700 lbs.
Small cast scrap	700 lbs.
Scrap rails	6 rails

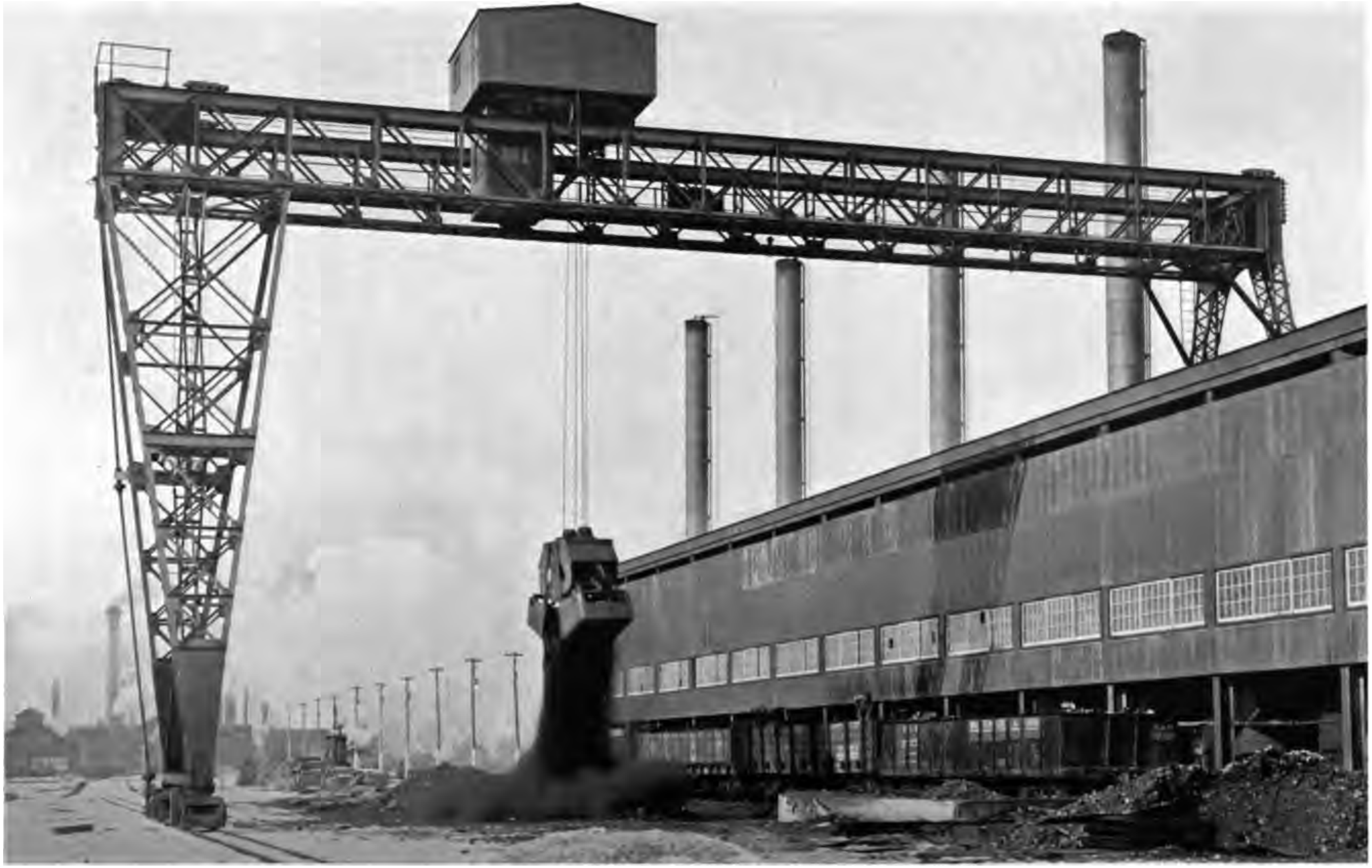
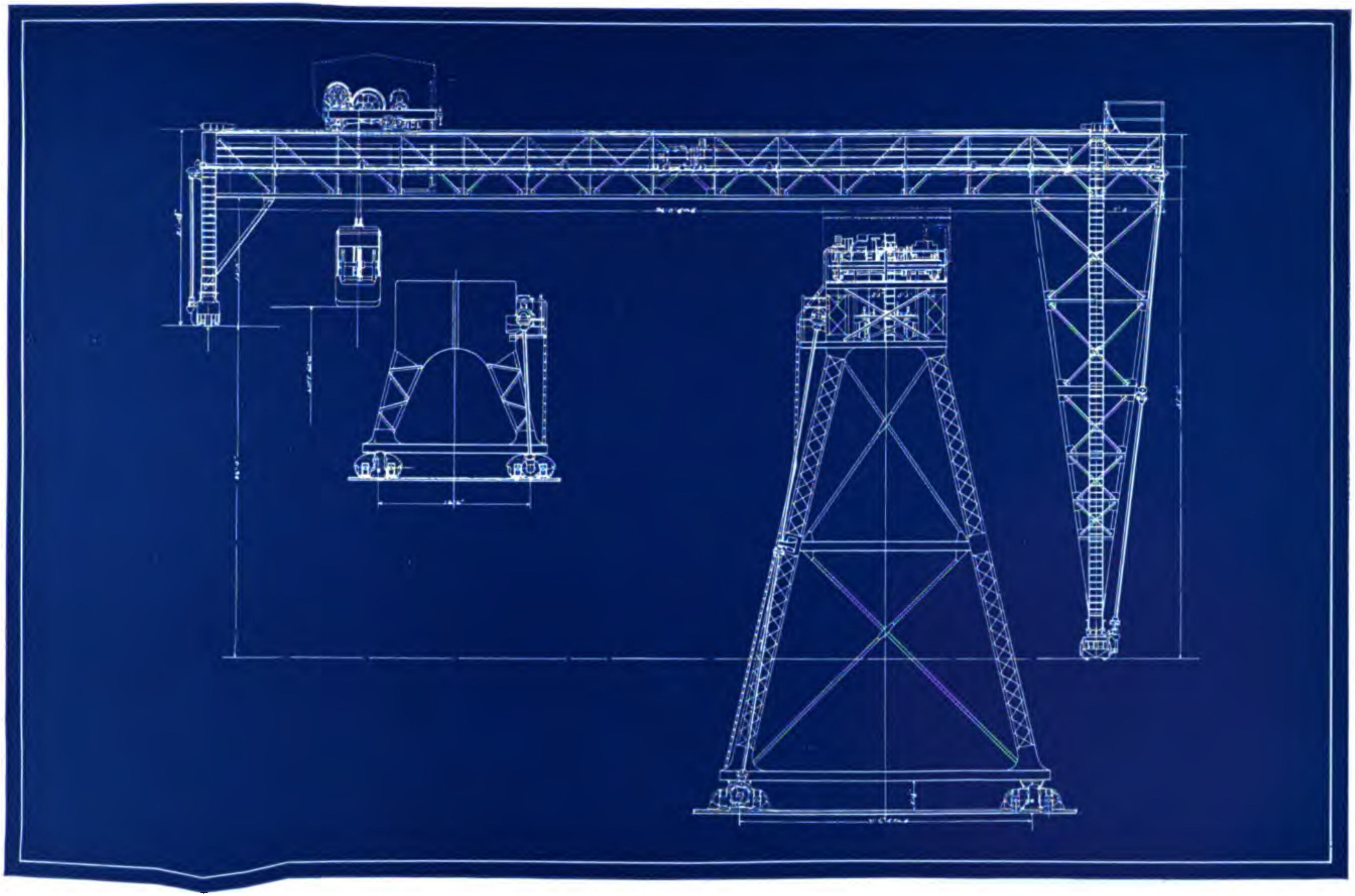


Figure 133—W-S-M BUCKET HANDLING CRANE

Special bucket handling cranes are used for many purposes at steel plants. This view shows a coal handling gantry equipped with a man trolley handling a 3-ton standard coal bucket. This crane was built for the National Tube



Co. at Lorain and is used for removing coal from road cars to stock and rehandling from stock into producer hoppers. The main span is 96 feet. The trusses are rigidly connected to the supporting legs, one of which travels on a surface runway, the other on top of the producer building. This machine has a capacity of about 250 tons an hour.

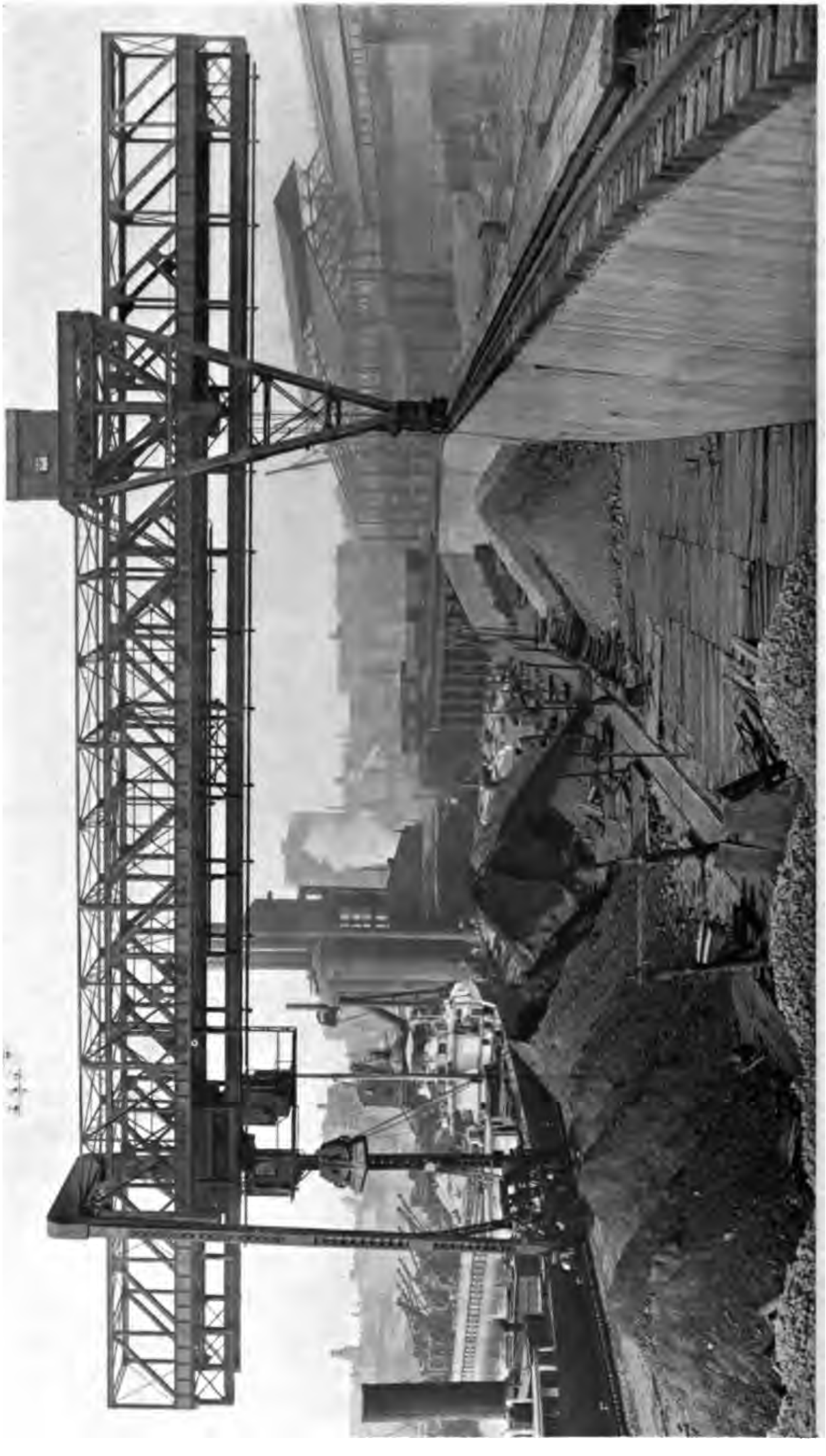
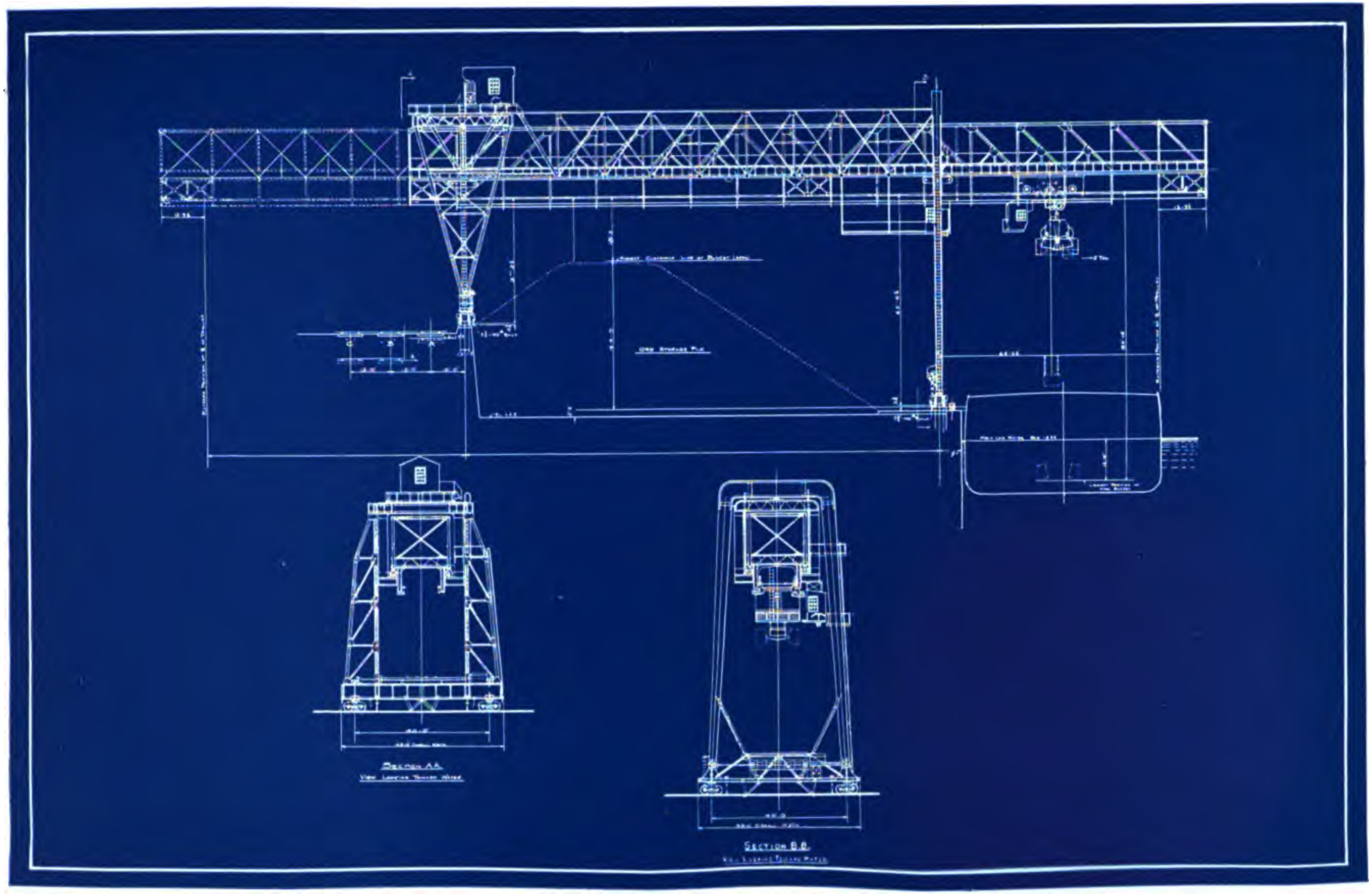


Figure 134—W-S-M ORE HANDLING BRIDGE

The ore handling bridge of the Upson Nut Company at Cleveland is equipped with a man trolley handling a 5-ton ore bucket. The pocket operating mechanism in the trolley is mounted on a turntable so that the bucket can be



rotated in a complete circle in order to obtain a greater reach under the hatches. The trolley runway is supported by a sliding boom which extends over the boat and can be drawn back to clear the face of the dock. The tower, and shear leg supporting the main span are provided with independent driving motors.

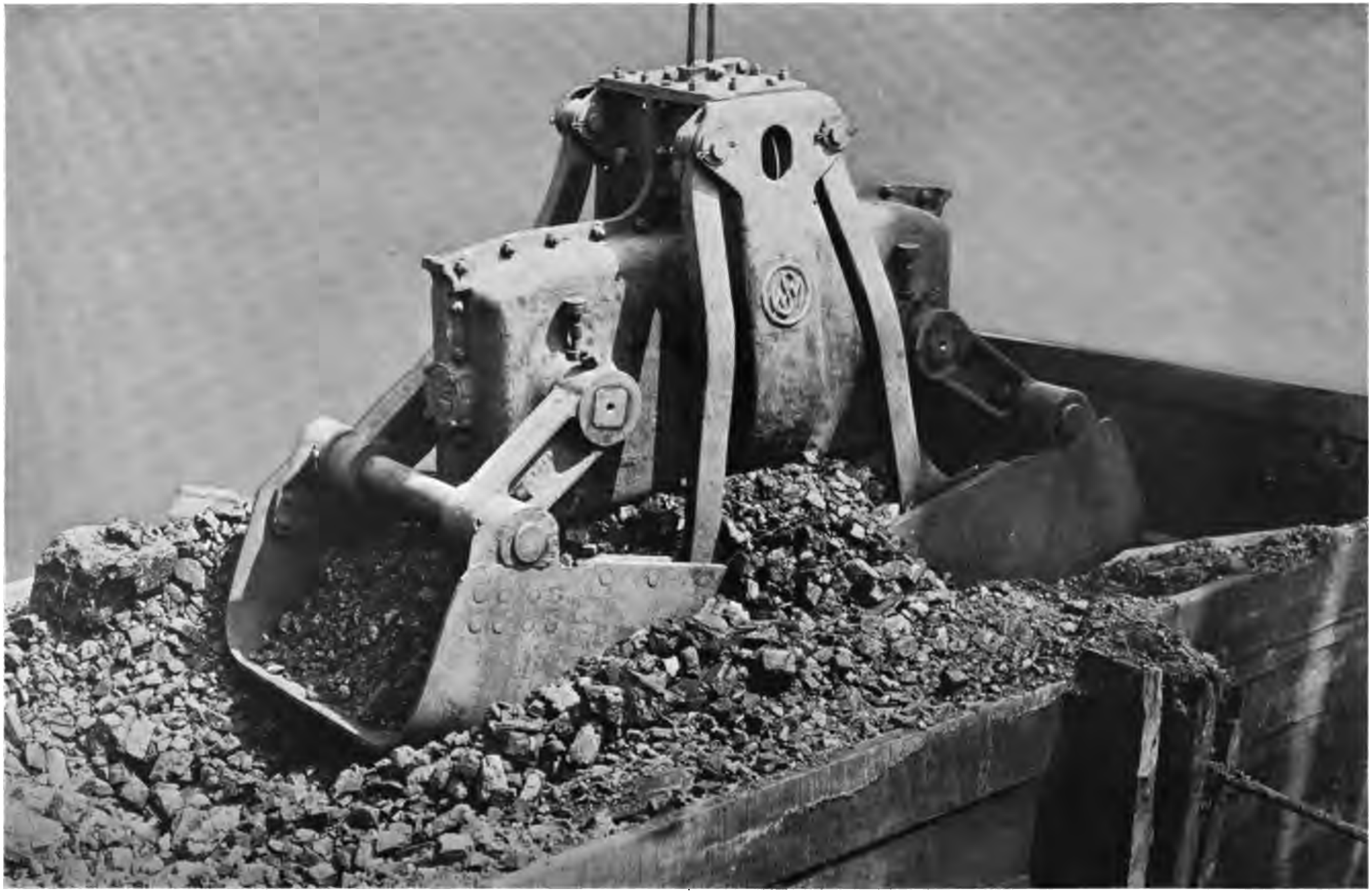
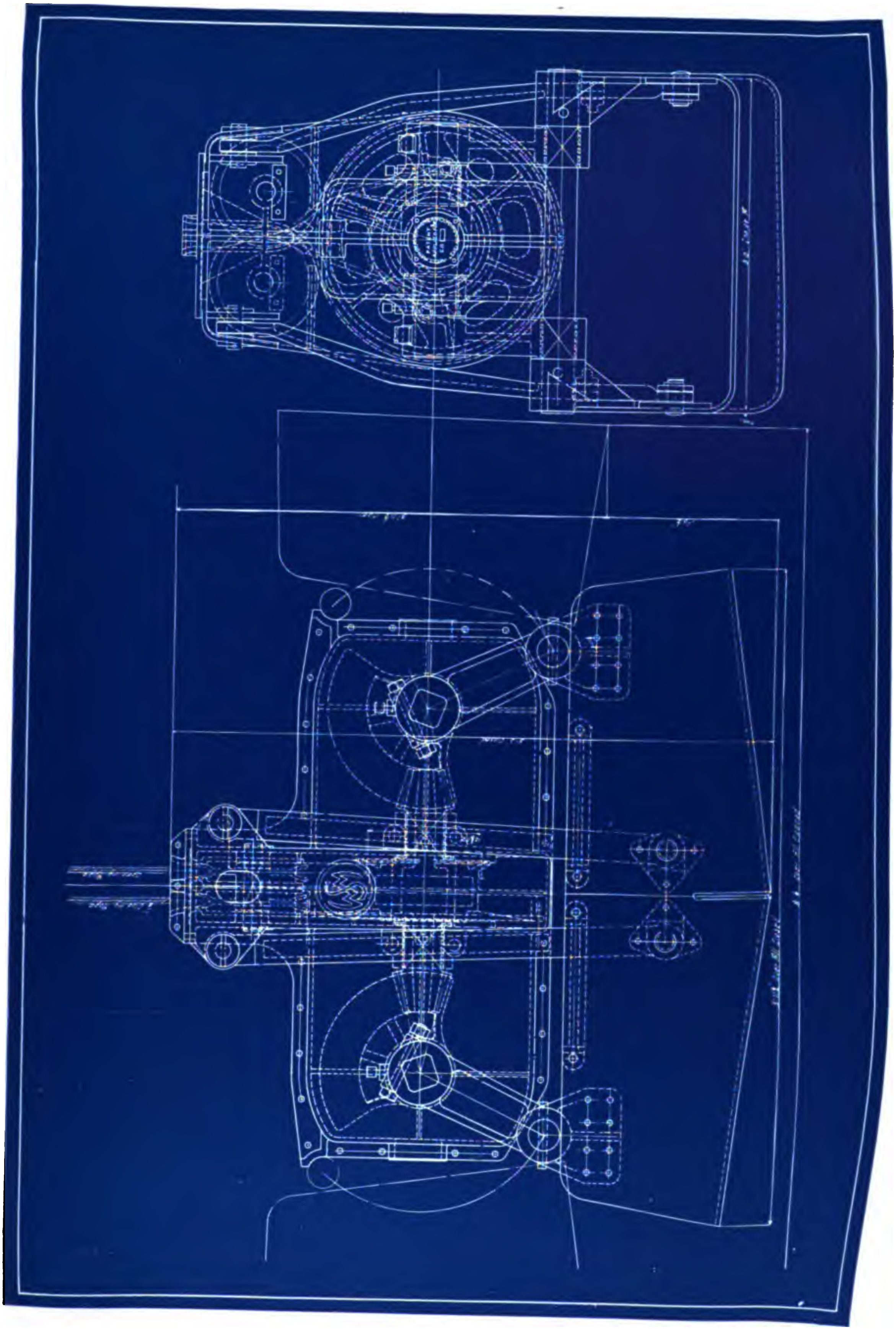


Figure 135—THE WELLMAN GEARED BUCKET

This bucket is designed to handle coal, sand, gravel or cinders. It is operated by completely enclosed gears driven by pinions forming the center of a power wheel upon which the opening and closing ropes are wound. It can be



operated by practically any type of two drum hoist. The principal features of this bucket are the elimination of wear on the operating parts due to contact with the material, the low center of gravity, the minimum head room, the small number of parts, the efficient digging path and accessibility.

Handling of scrap and pig iron should be done entirely by electro-magnets carried by and operated from the cranes serving the yard. For furnace charging the charging boxes are placed side by side close together, four to a car.

The value of scrap aside from its chemical composition, is determined by its physical condition. Material of a form to fill a charging box with a minimum of void and of individually heavy pieces is most suitable for furnace working. Light thin scrap, such as stamping from can-making or sheet metal works, should be compressed and firmly baled in bundles approaching the condition of the heavy scrap. It is easy to handle and decreases the loss from oxidation during melting.

The United States Steel Corporation scrap classification gives the relative value of various kinds of scrap, used by its subsidiary companies, which is given below:

Table No. 71

Scrap Classification

Pig Iron Value Taken as 100%

105%	Condensed ingots Bloom crops Rail ends Broken old rails	Defective billets Structural shape scrap Forge scrap Etc.
100%	Broken moulds Broken stools Plate scrap Skelp scrap Sheet bar crop ends	Muck bar croppings Rod cobbles Eye bar crops Tube and socket mashed crops Off grade pig iron
95%	Merchant mill scrap Spike and bolt scrap Horse shoe scrap Rolls, pinions, steel castings	Galvanized pipe scrap Light eye bar scrap Light structural scrap broken to charging box size
90%	Chilled ladle skulls Broken rolls Iron castings	Broken salamanders Pinions
85%	Hoop and cotton tie scrap Black and tin sheet scrap Fine pig iron scrap Furnace runner scrap	Rod mill scrap bundled for charging boxes Casting machine scrap
80%	Pipe scrap Bundle wire scrap Nail scrap	Light ladle scrap Light ladle skulls
75%	Light iron and steel castings	Wrought iron scrap
70%	Nail whiskers Skull cracker scrap Turnings	Bessemer and open hearth pit scrap Drillings Steel borings
60%	Iron drillings	Iron turnings and borings
50%	Burnt iron Galvanizing pots	Worn out annealing boxes all broken to fit charging boxes
30%	Old corrugated roofing Converter slag Open hearth run-off slag Cupola slag Converter spittings Alley scrap	Pit, tap, flue cinder of ore 50% iron and for basic use Not over 5% silica Metal mixer slag Rod mill scale Rolling mill scale

All of above materials must be of charging box size and if not a reduction will be made in the credit for same.

CHAPTER XXIV

Illustrations of Open Hearth Furnaces

In this treatise tabulations and views illustrating American and European practice are presented. A study will reveal many differences.

A general tendency is shown towards the adoption of proportions and ratios existing between important features of furnaces, which have given good results in steel making.

The wide disparity in the principal dimensions of a number of 50-ton furnaces is given in table No. 46. As the metallurgical and economical aspects of the performance of various furnaces are more closely studied, these wide divergences will disappear and a composite design will be evolved.

A review of the open hearth furnaces in American steel casting foundries as of January 1st, 1919, shows a total of 221 furnaces as follows:

Table No. 72

Type of Furnace	Number of Furnaces	Tonnage Per Heat	Daily Total Tonnage
Acid lined furnaces	90	..	..
Basic lined furnaces	53	..	..
Lining not reported	78	..	..
Total	221	4986	10,000

In this tabulation, furnaces are not listed of those large steel companies who use their commercial furnaces for their own shop requirements.

The distribution of the furnaces according to size of those enumerated are:

1 ton per heat	1 furnace
2 tons per heat	1 furnace
3 tons per heat	1 furnace
4 tons per heat	3 furnaces
5 tons per heat	5 furnaces
6 tons per heat	1 furnace
8 tons per heat	2 furnaces
10 tons per heat	13 furnaces
12 tons per heat	2 furnaces
15 tons per heat	18 furnaces
18 tons per heat	4 furnaces
20 tons per heat	41 furnaces
25 tons per heat	89 furnaces
30 tons per heat	26 furnaces
35 tons per heat	2 furnaces
40 tons per heat	7 furnaces
50 tons per heat	5 furnaces
Total	221 furnaces

Thus it appears that American steel foundry practice is best served with furnaces of 20 to 30 tons capacity per heat, while in plants of moderate size 15-ton furnaces best meet the average conditions.

Steel works, making ingots for rolling mills, working direct process furnaces, lean towards a size of furnace of 50 to 70 tons capacity. The most advantageous size for Talbot furnaces operating in the duplex or triplex process approximates 200 to 250 tons capacity.

Reproductions of some open hearth furnace designs ranging from 5 to 300 tons capacity, are given together with some layouts for steel foundries and steel plants.

These views show the range of Wellman practice, and also the alterations of design to meet the specific conditions.

Progress pictures showing the erection of a twenty-ton open hearth furnace are given, as many interesting details of furnace design are quite clearly shown. (Pages 300 to 310.)

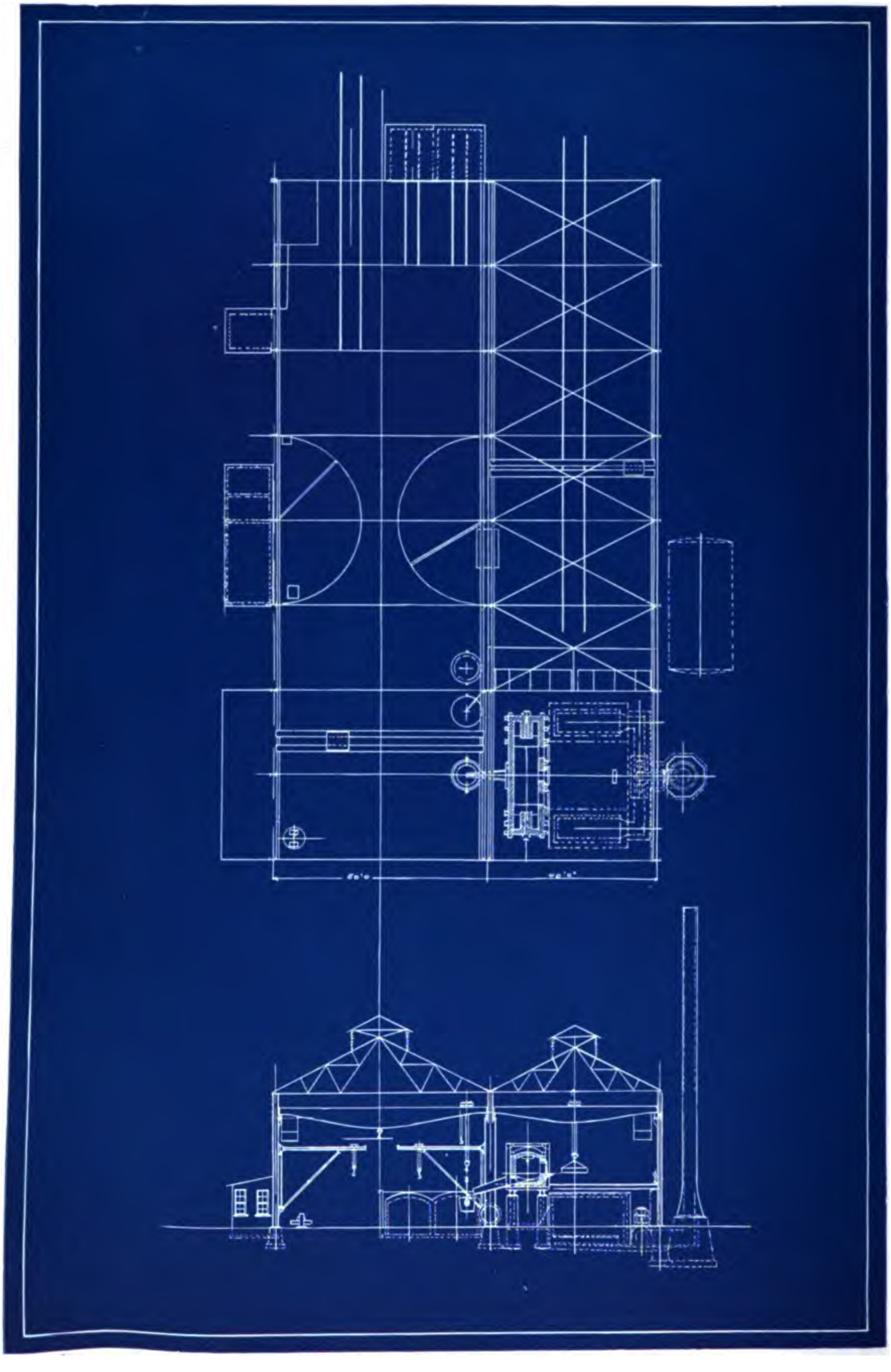


Figure 136—LAYOUT OF A 5-TON BASIC OPEN HEARTH STEEL FOUNDRY

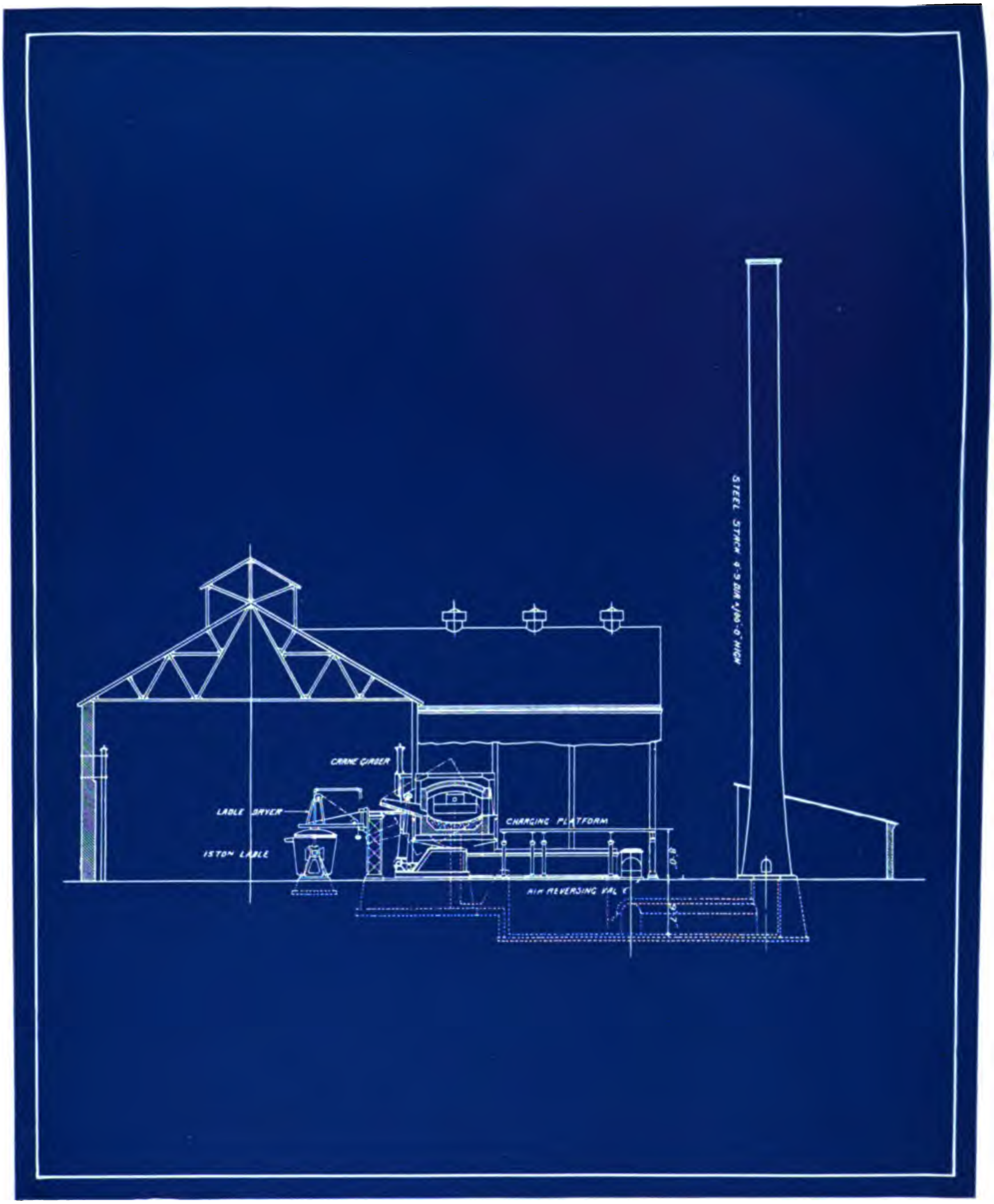


Figure 137—LAYOUT FOR 15-TON OPEN HEARTH FURNACE

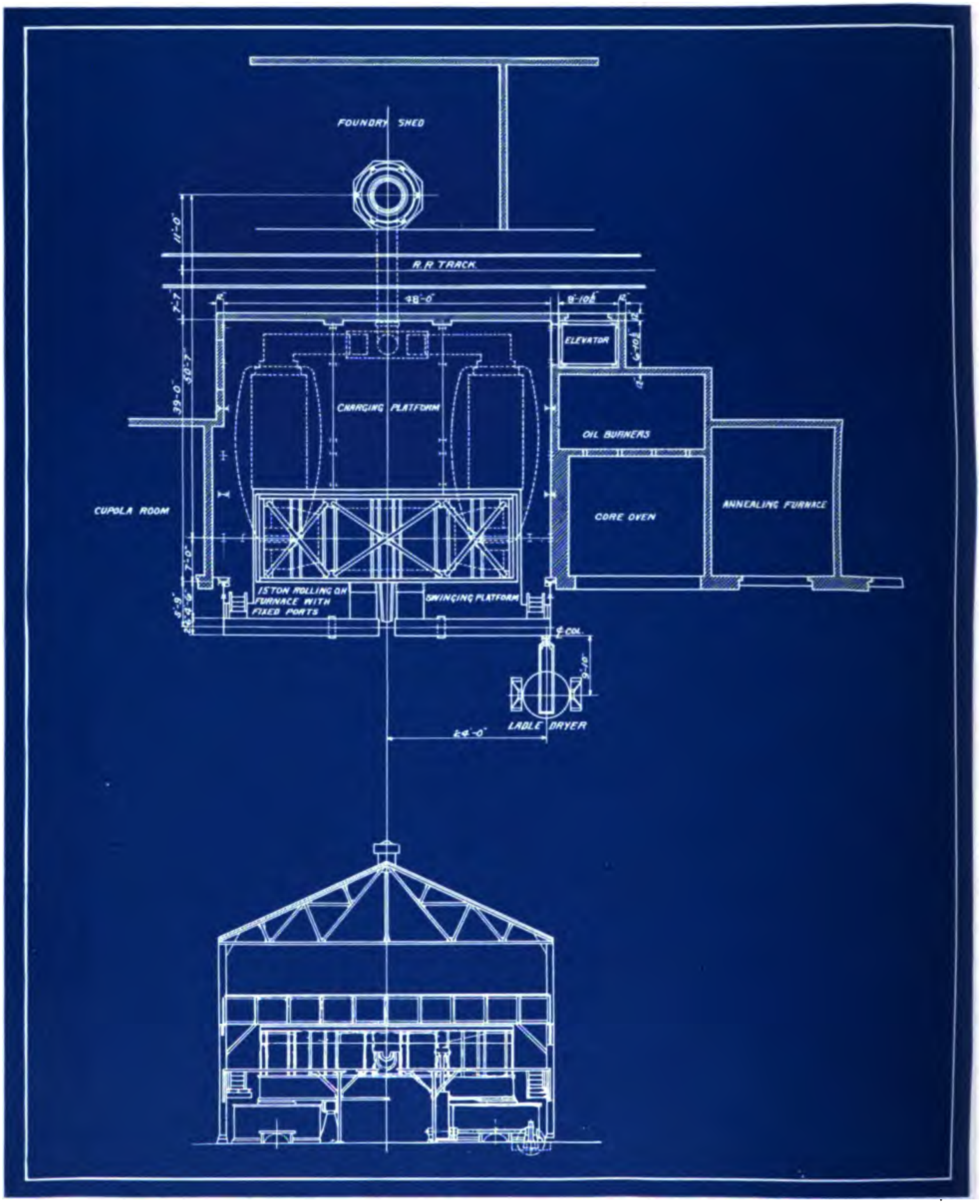


Figure 138—15-TON TILTING WELLMAN FURNACE

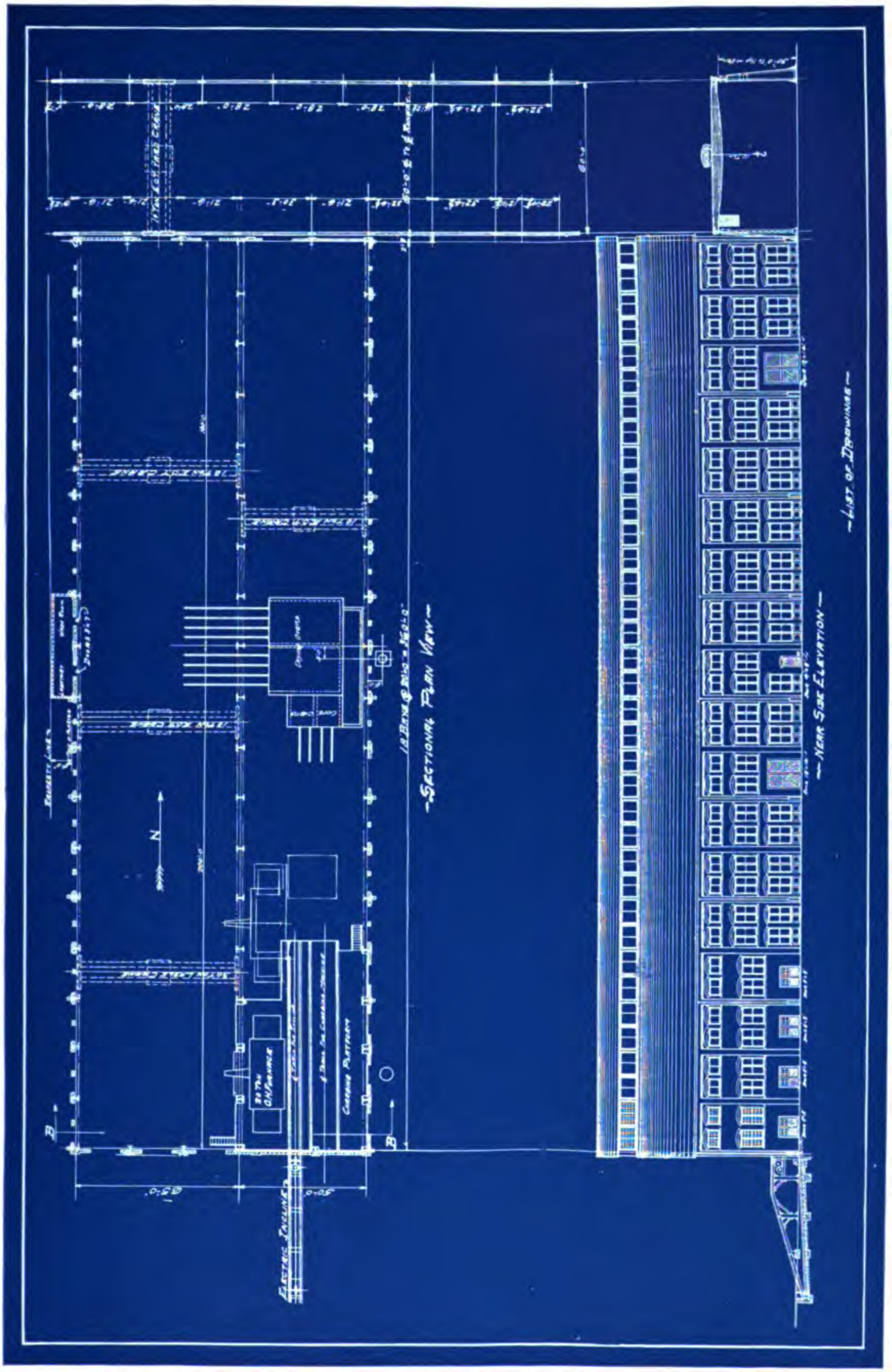


Figure 139—20-TON FURNACE STEEL FOUNDRY

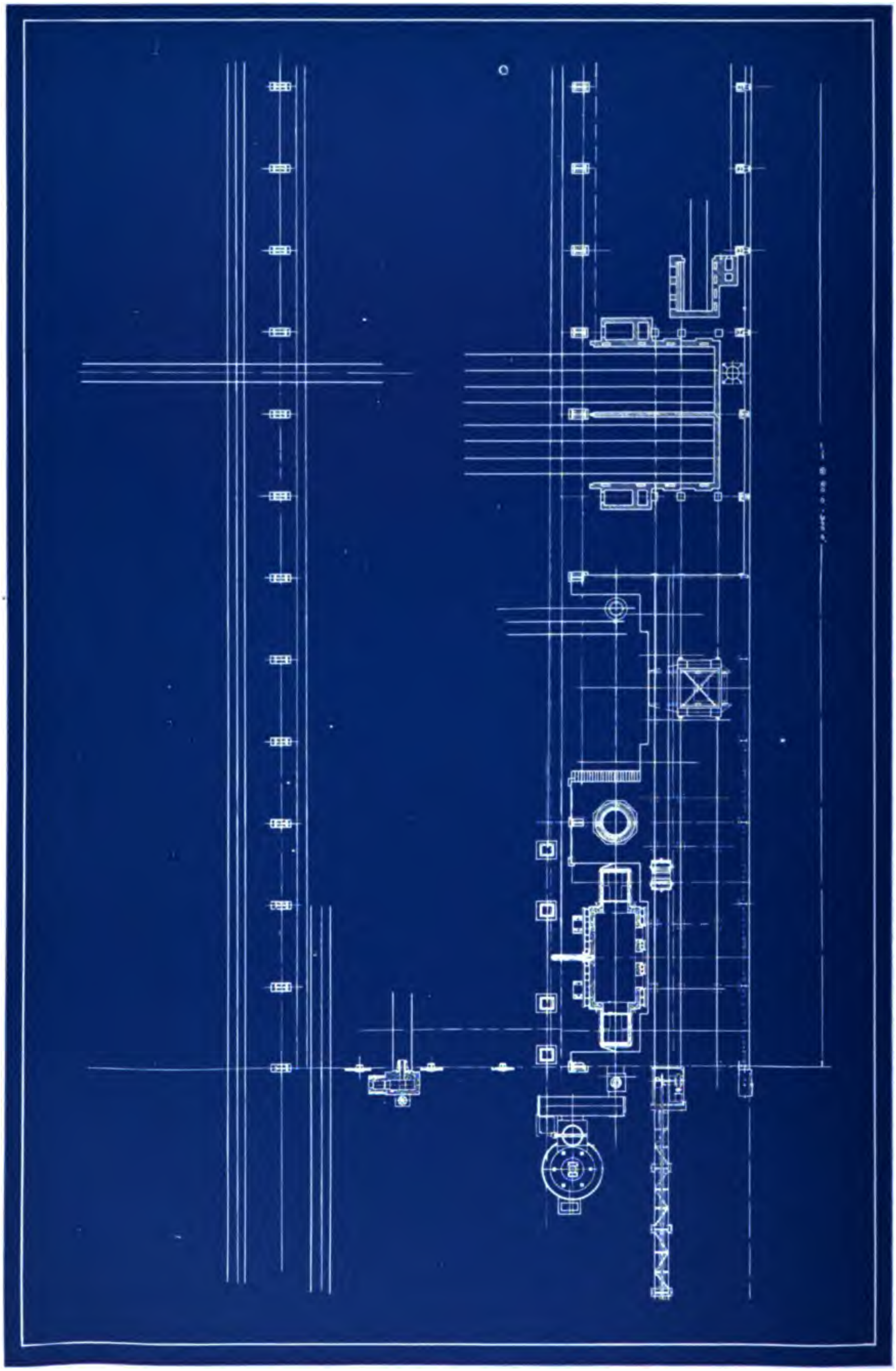


Figure 140—20-TON OPEN HEARTH FURNACE AND STEEL FOUNDRY

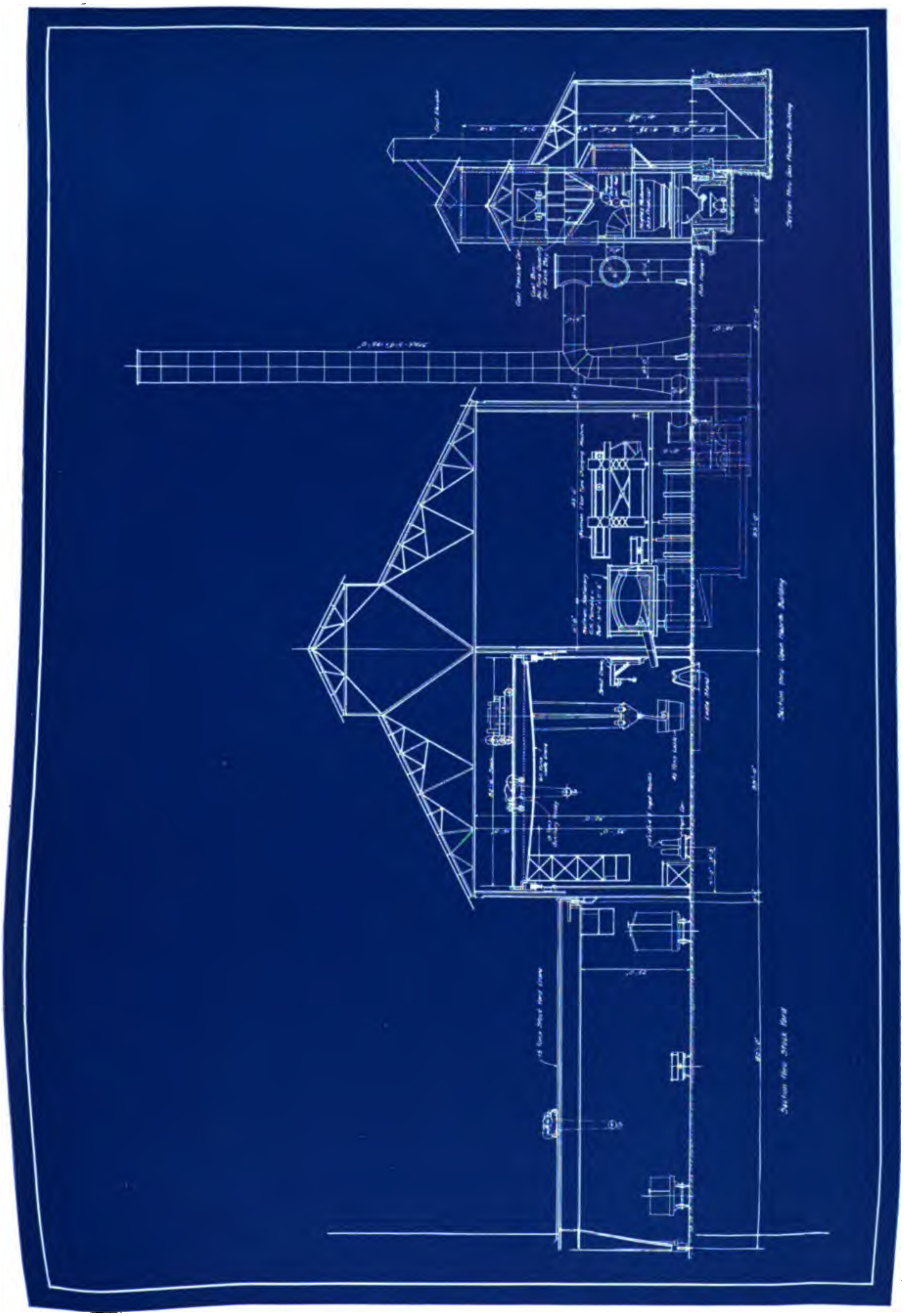


Figure 141—30-TON FURNACE PLANT

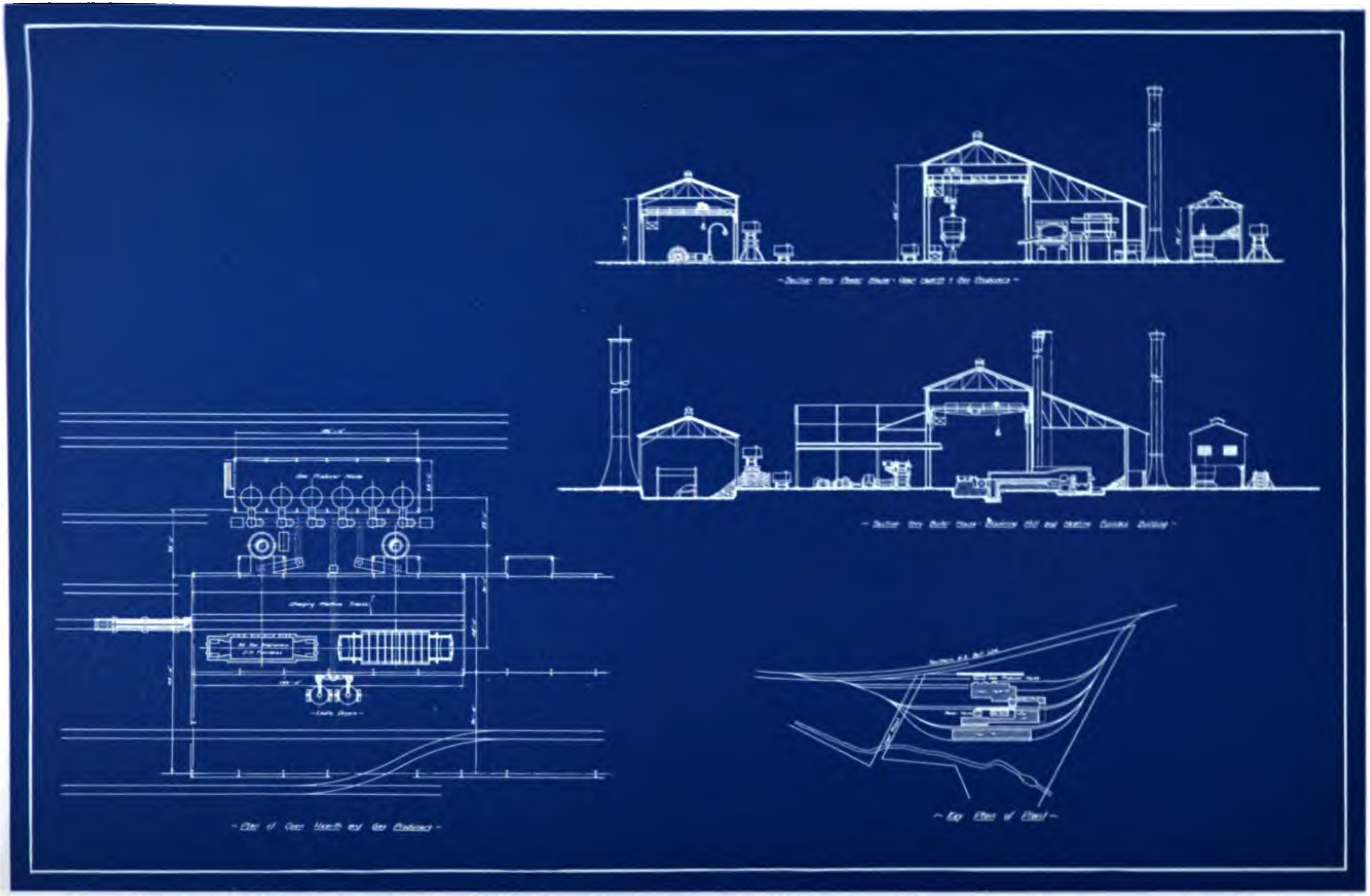


Figure 142—GENERAL DRAWING OF STEEL PLANT AND BLOOMING MILL

Two 35-ton furnaces.

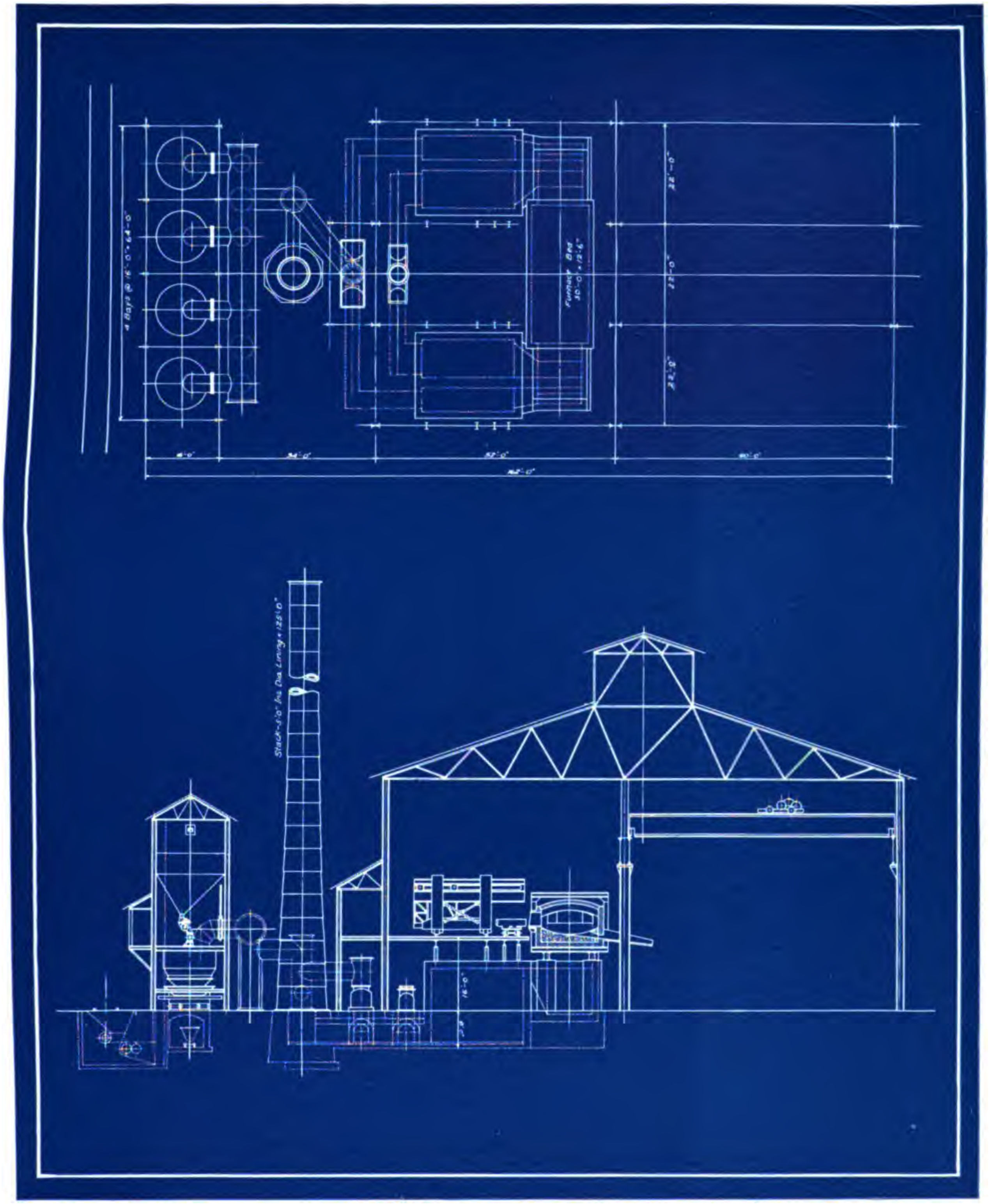


Figure 143—40-TON FURNACE AND GAS PRODUCERS

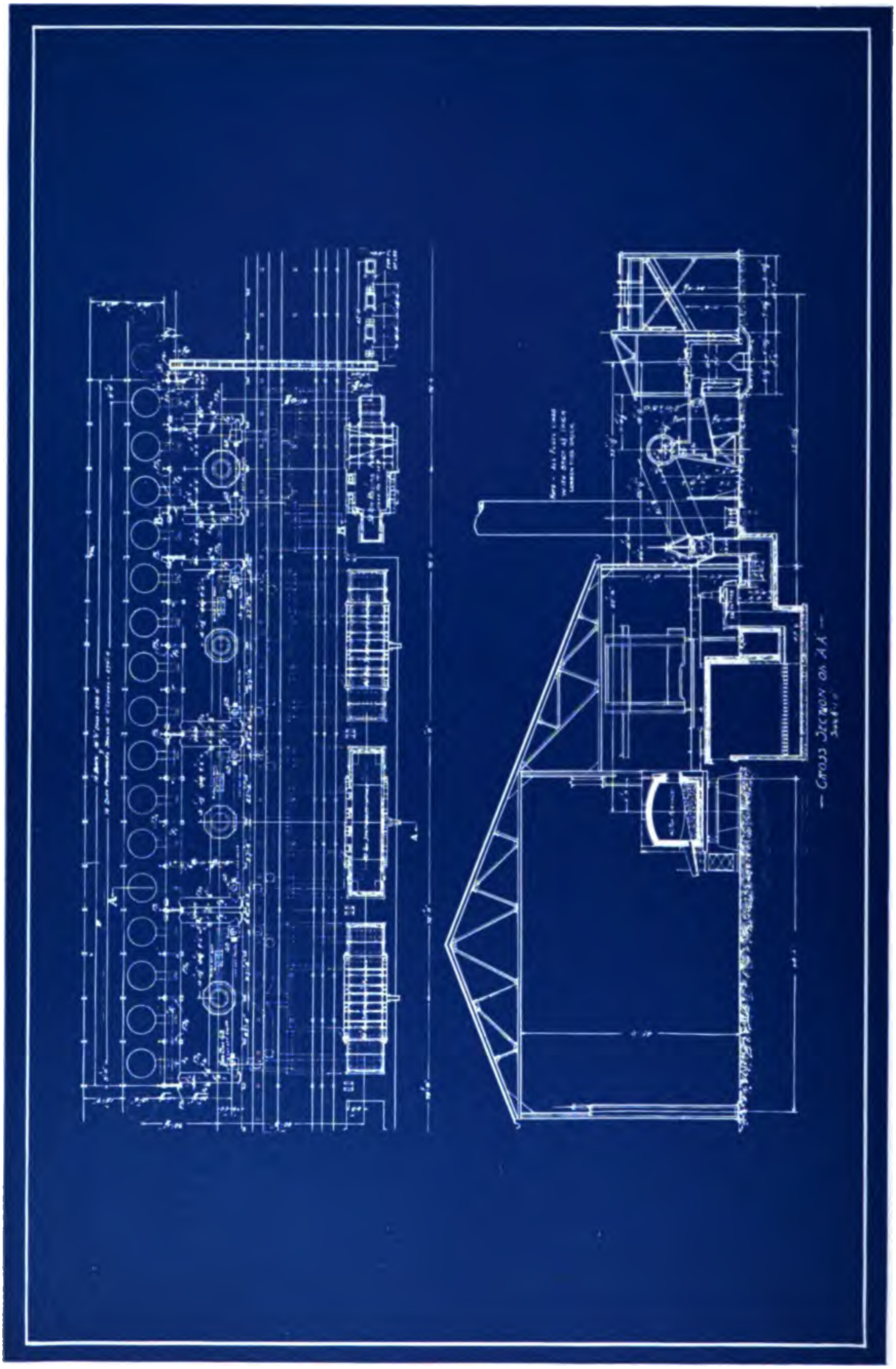


Figure 144—40- and 50-TON FURNACE STEEL PLANT

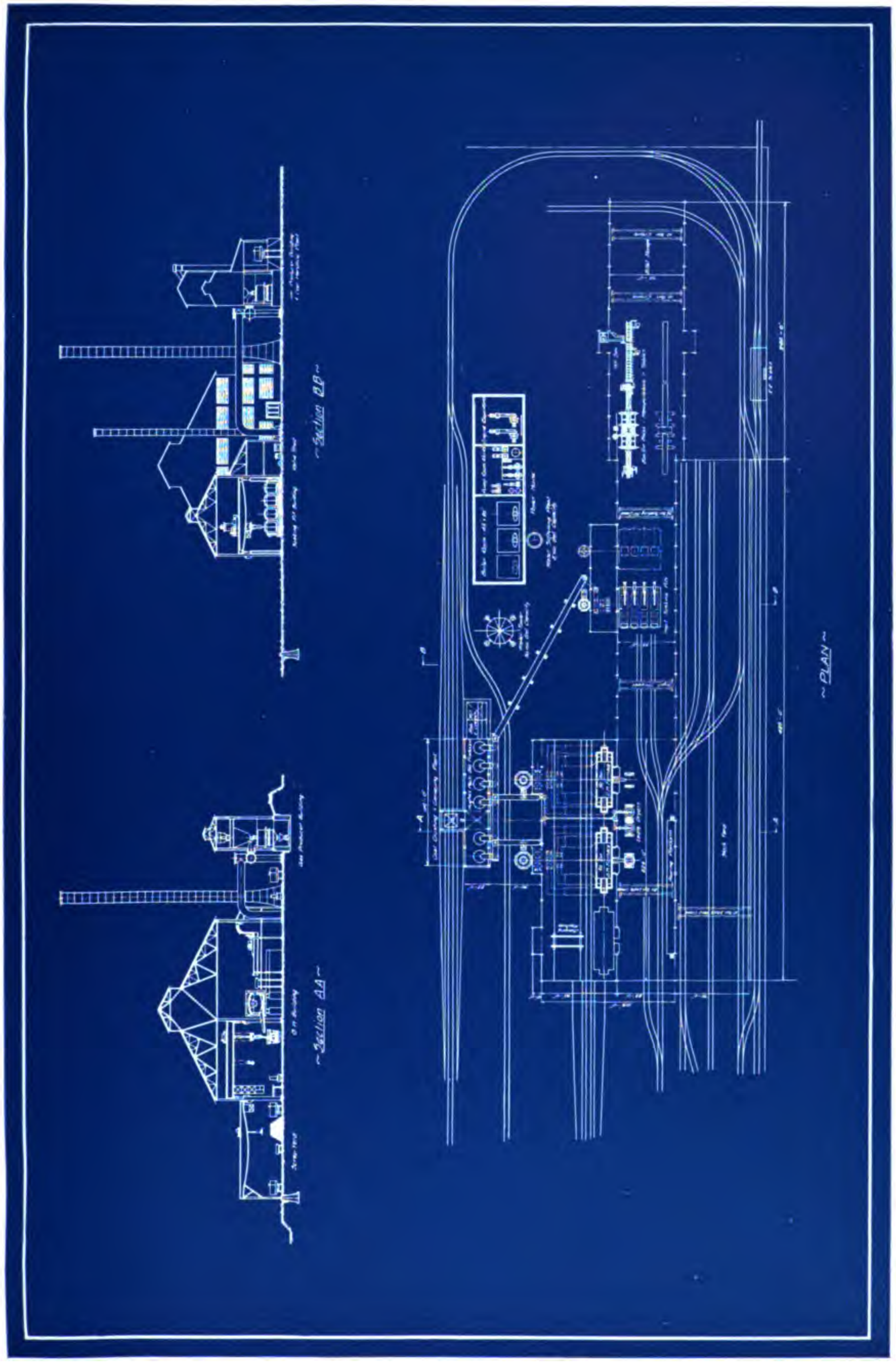


Figure 145—THREE 50-TON FURNACE OPEN HEARTH STEEL PLANT

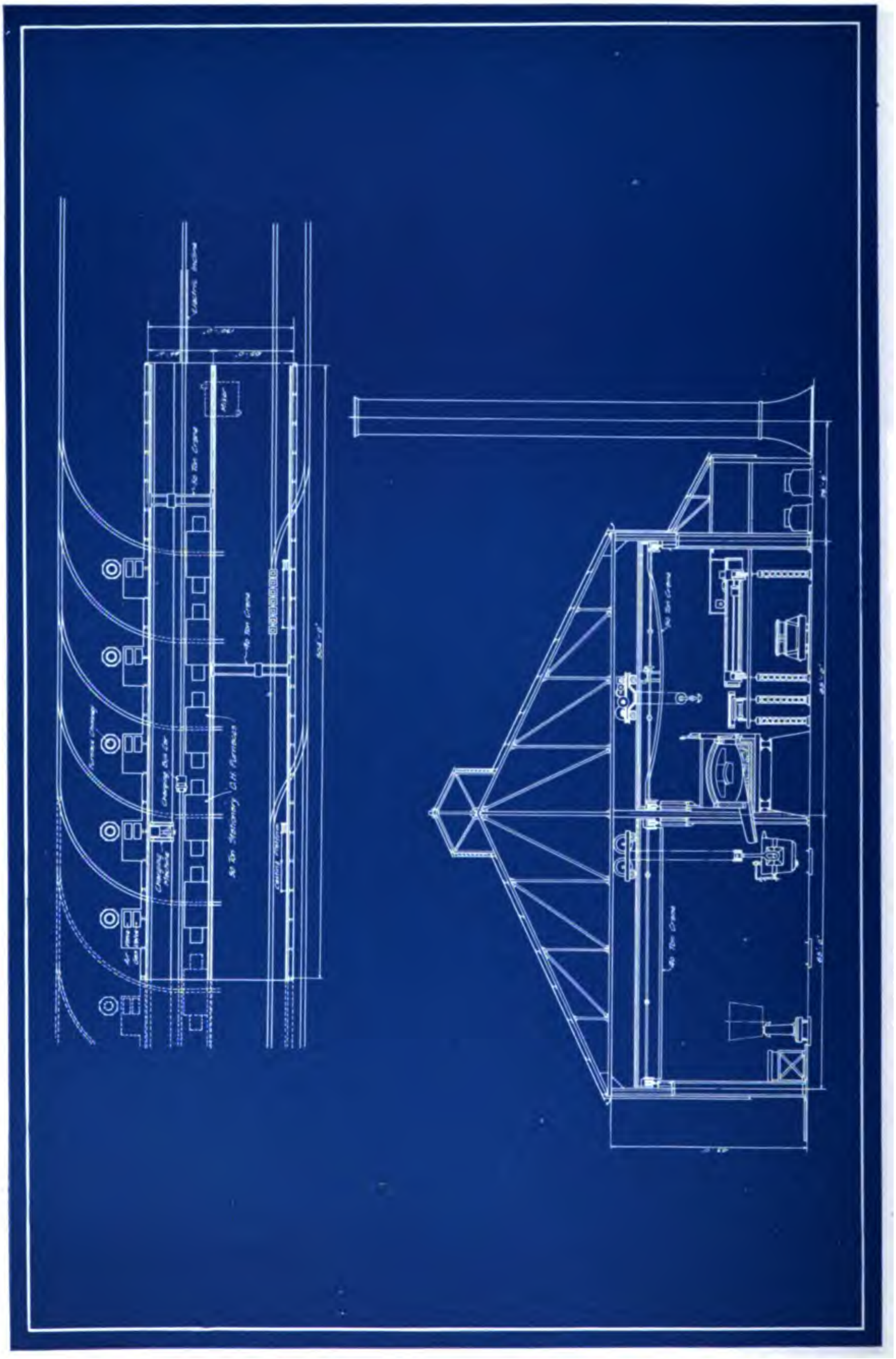


Figure 146—FIVE 50-TON FURNACE PLANT

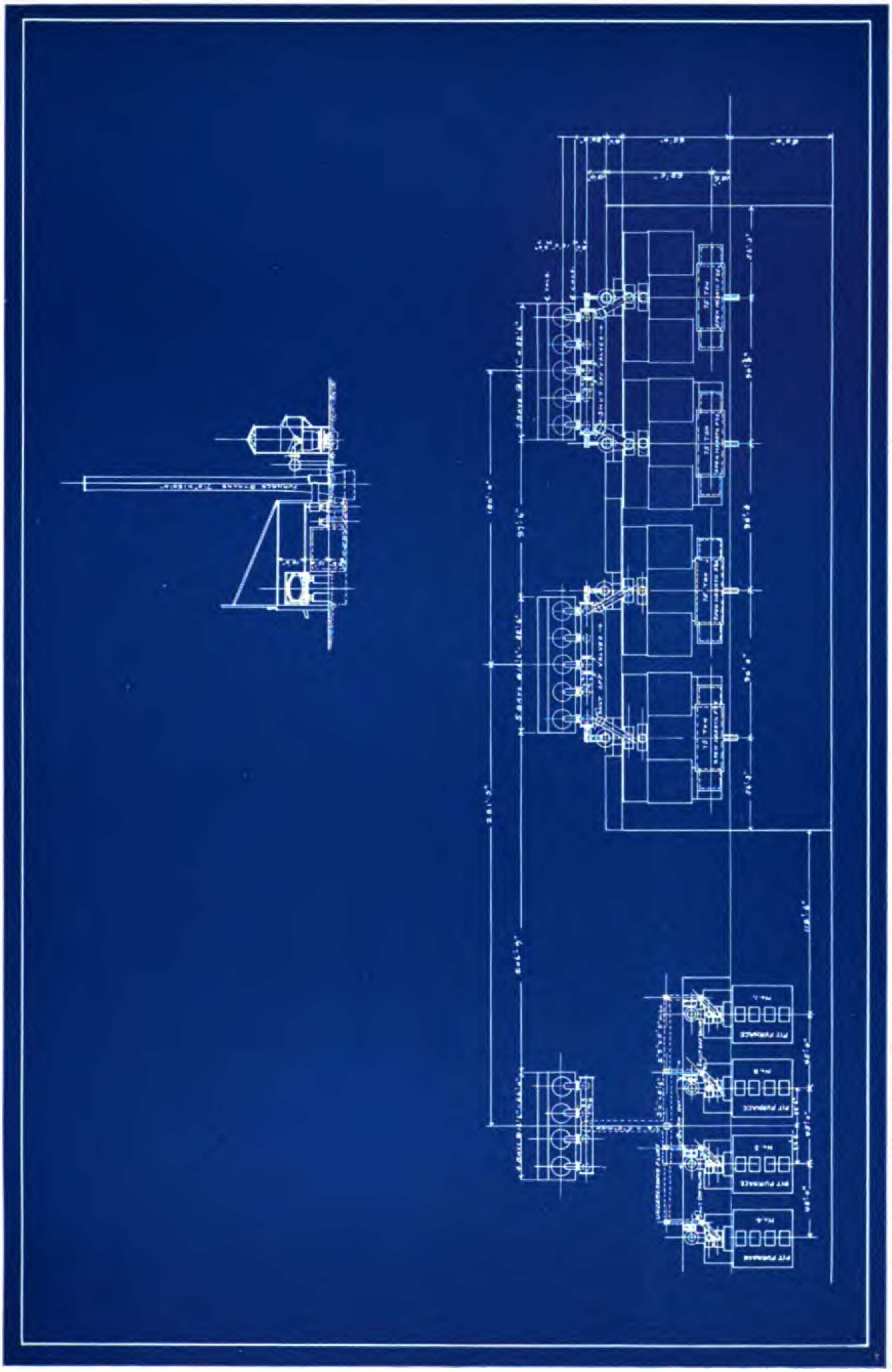


Figure 147—FOUR 75-TON OPEN HEARTH FURNACE LAYOUT

With 4 soaking pit ingot heating furnaces.

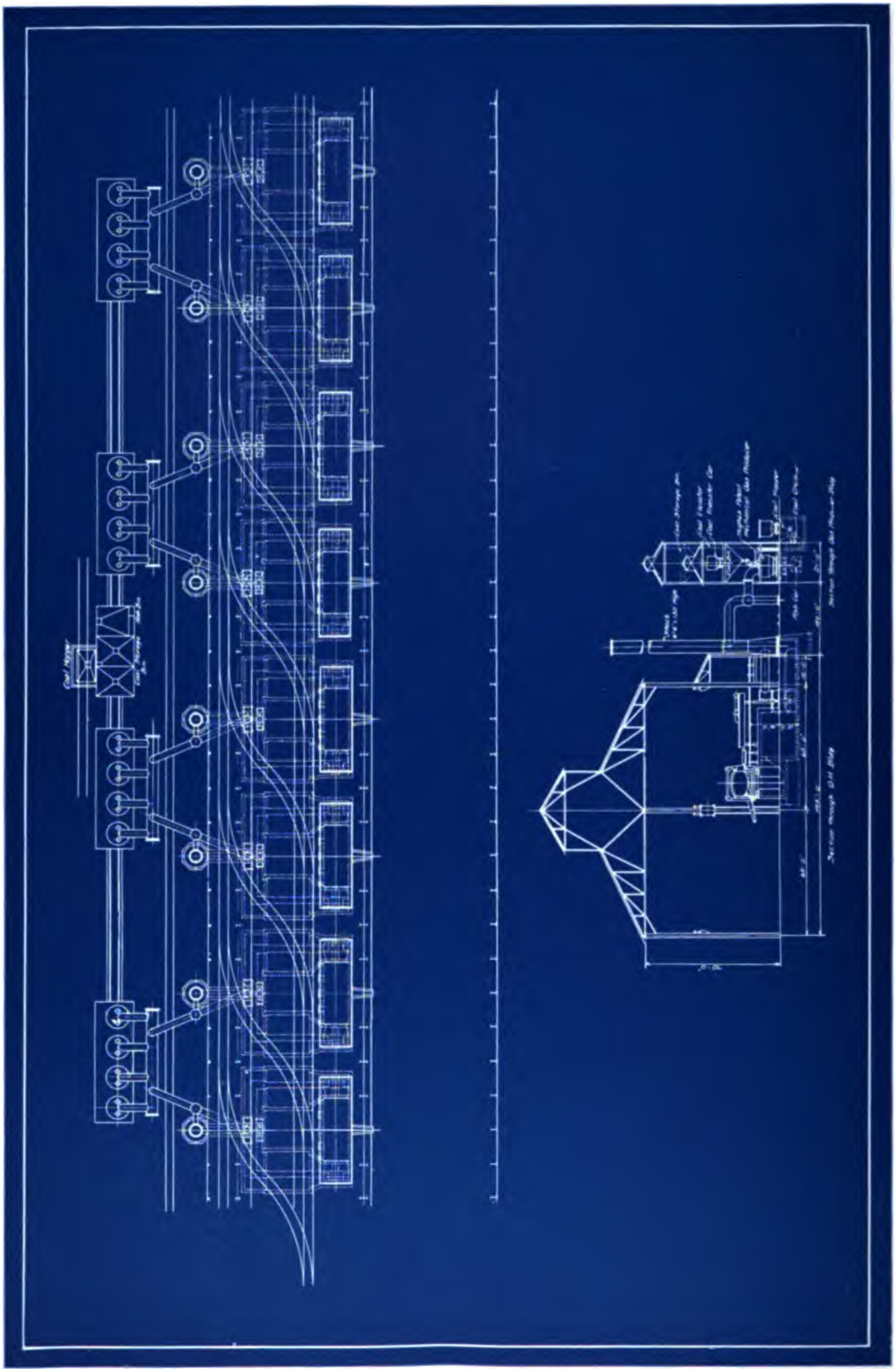


Figure 148—EIGHT 50-TON FURNACE OPEN HEARTH PLANT

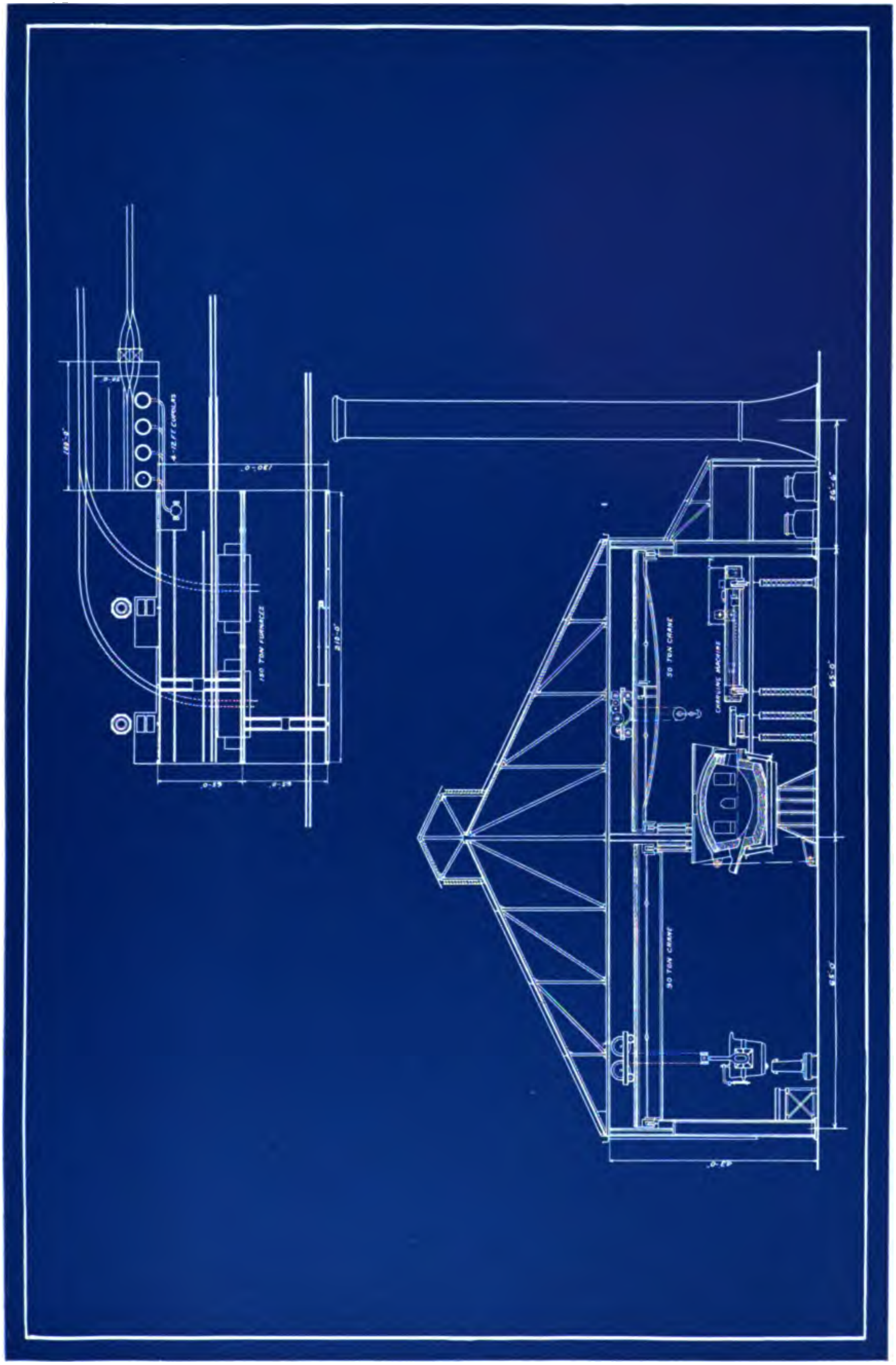


Figure 149—TWO 150-TON FURNACE OPEN HEARTH STEEL PLANT

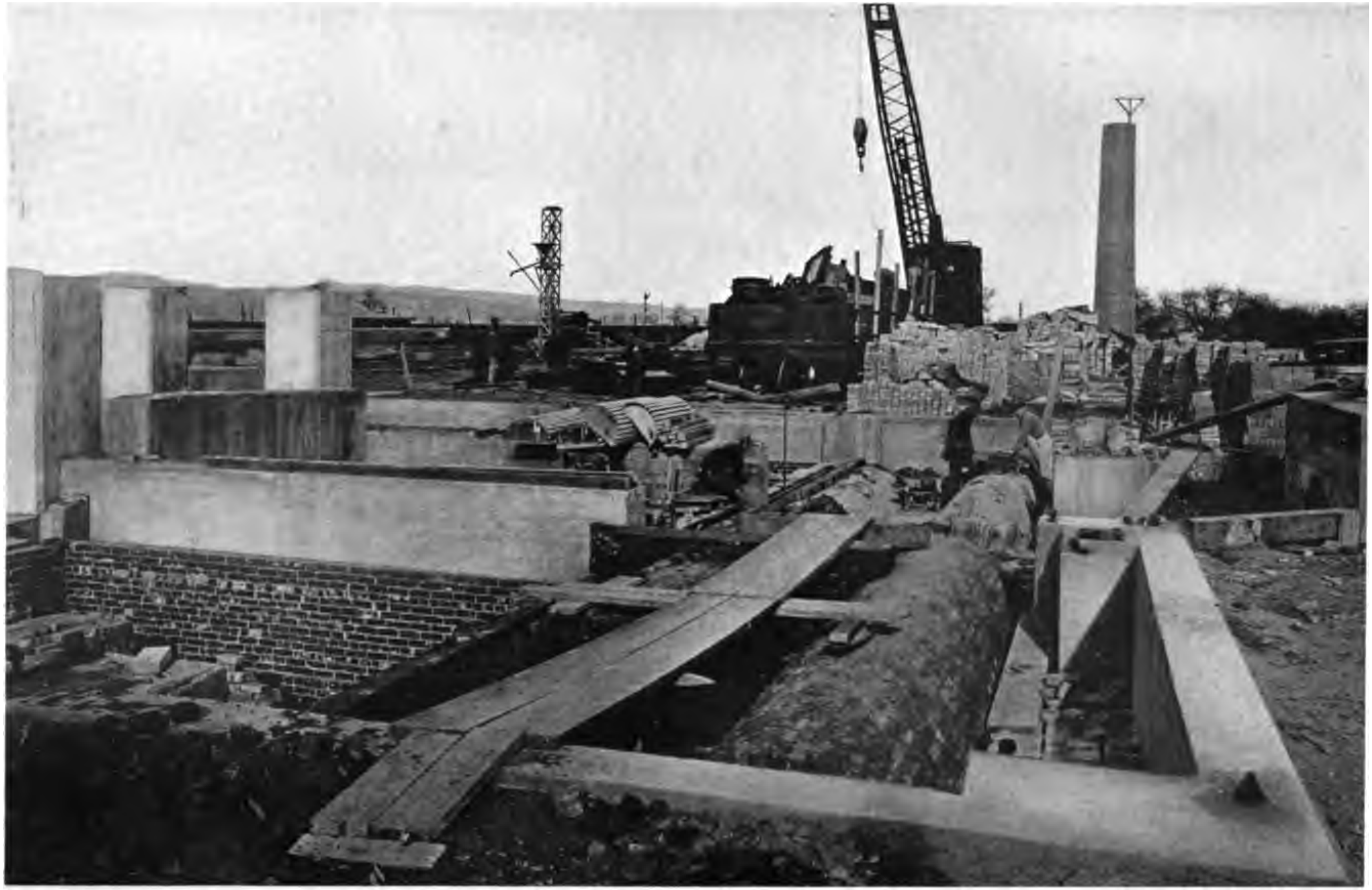


Figure 150—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Showing foundations and flues. The furnace stack is of radial brick similar to the one in the background which is for annealing furnaces.

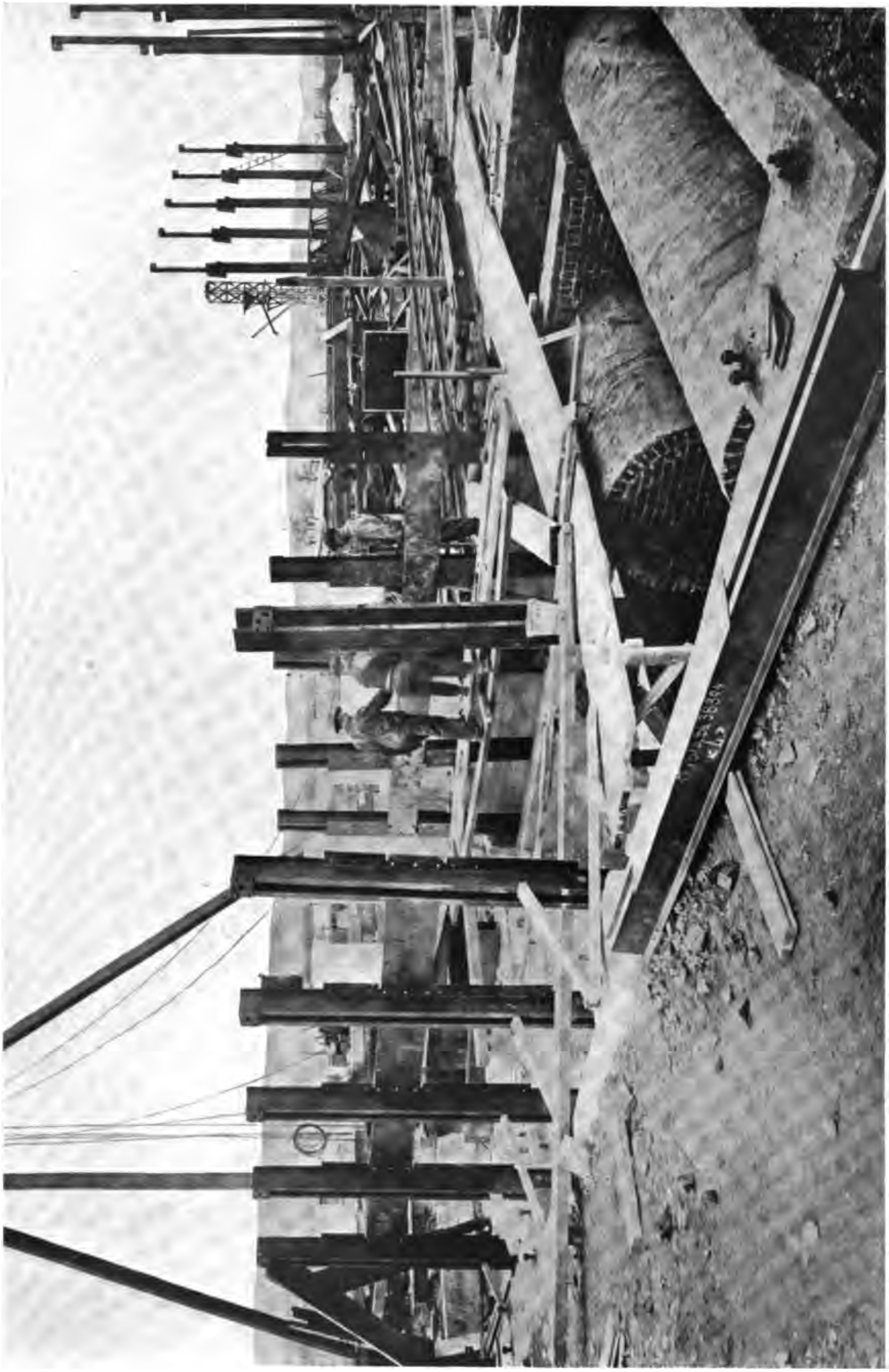


Figure 151—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Showing the placing of regenerator binding.

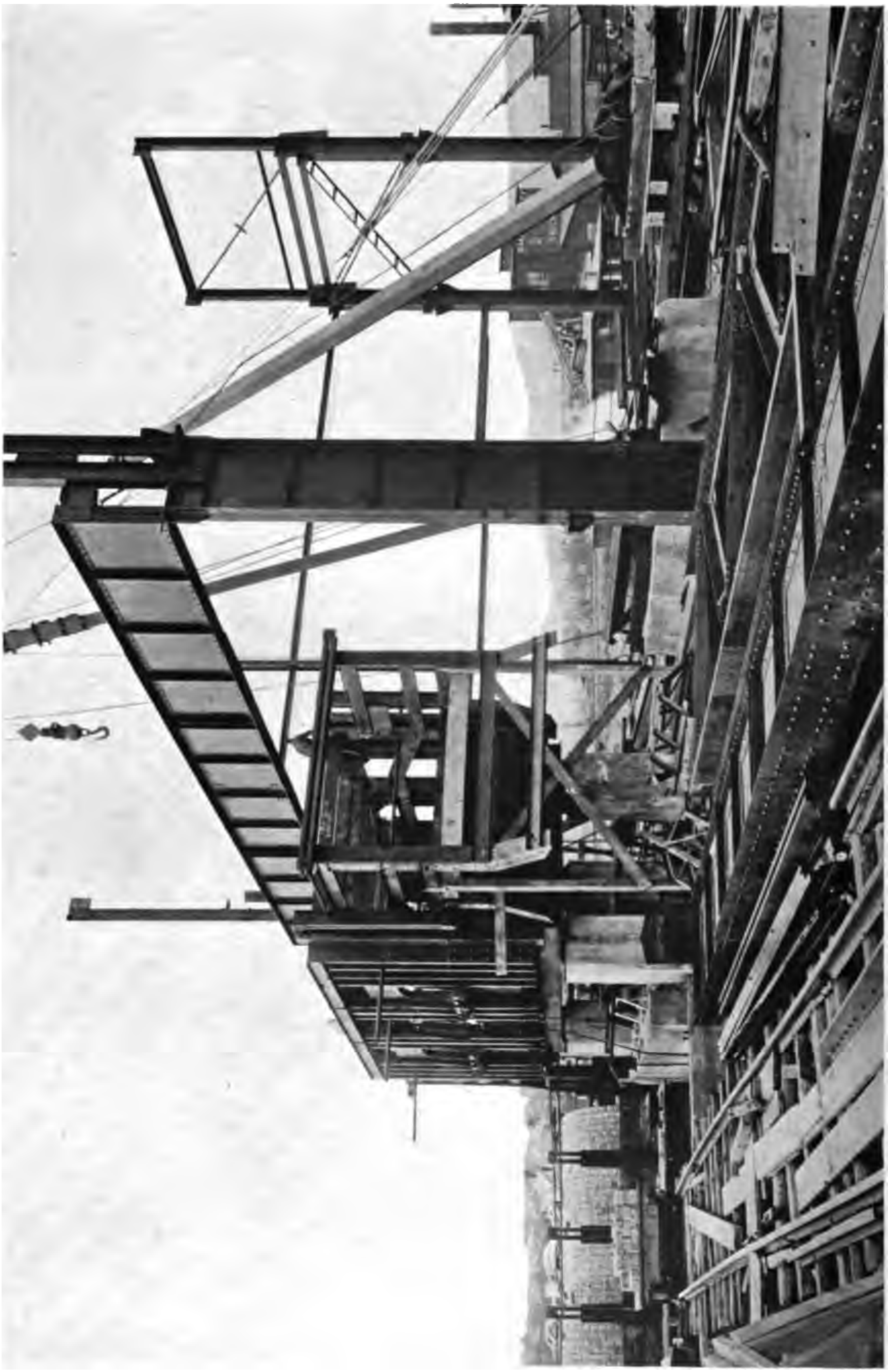


Figure 152—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Port end and steel binding in place. Arched roof on one regenerator ready for the red brick covering.

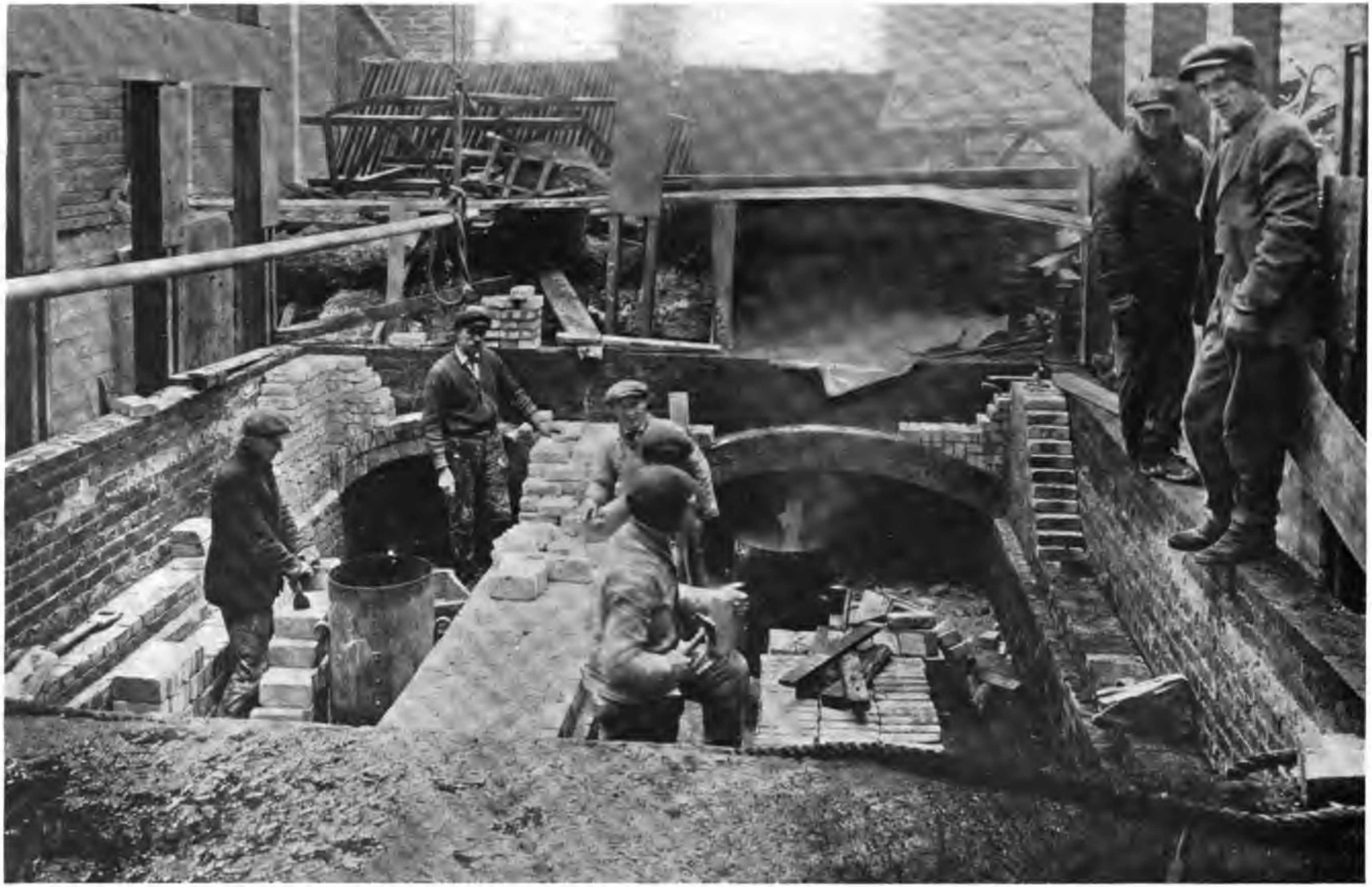


Figure 153—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

The start of the fire brick inside walls of the regenerators. The especially heavy wall between the air and gas chambers prevents cross leakage of gas.

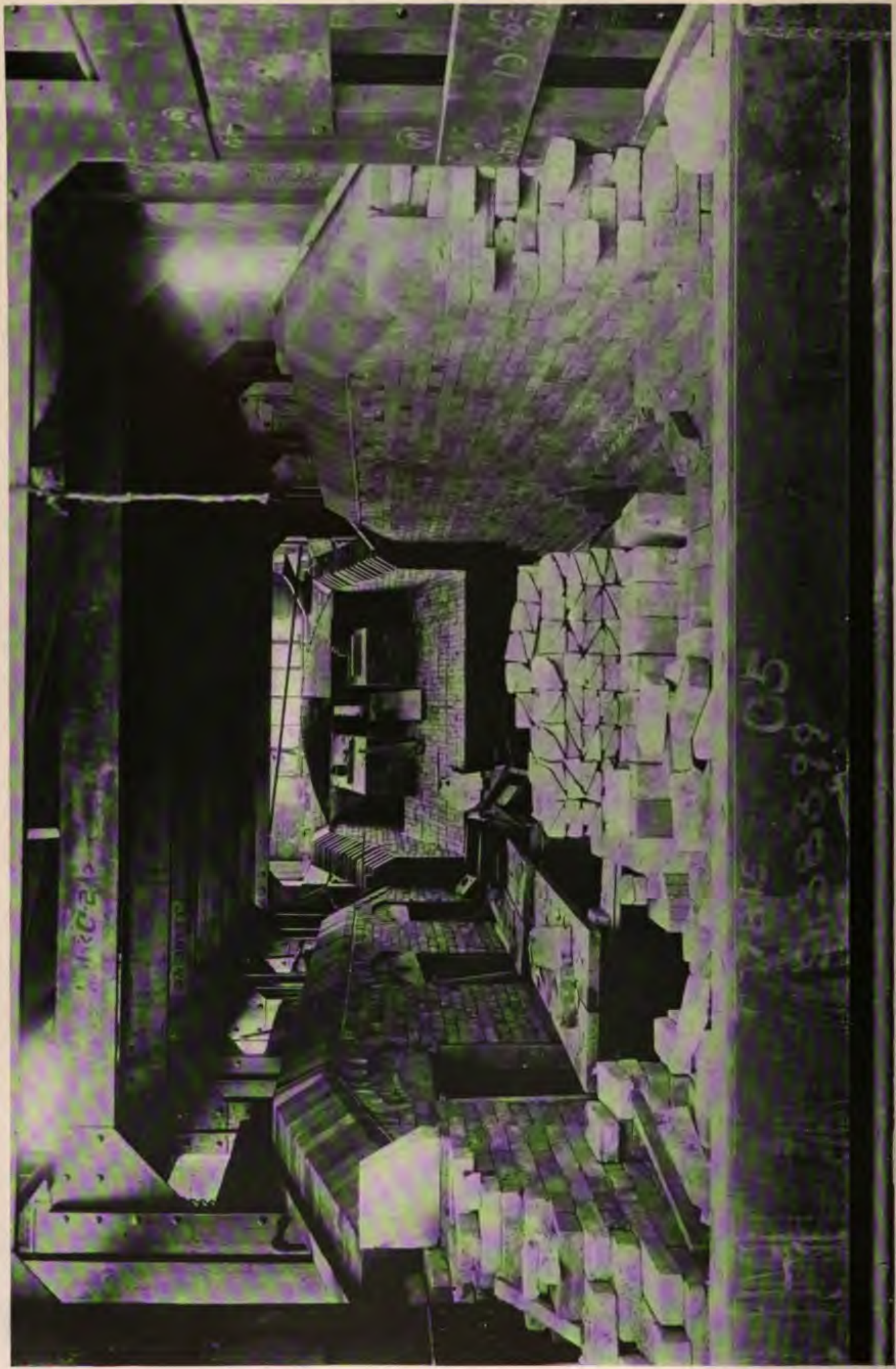


Figure 154—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Showing furnace walls and skew backs of roof arch.

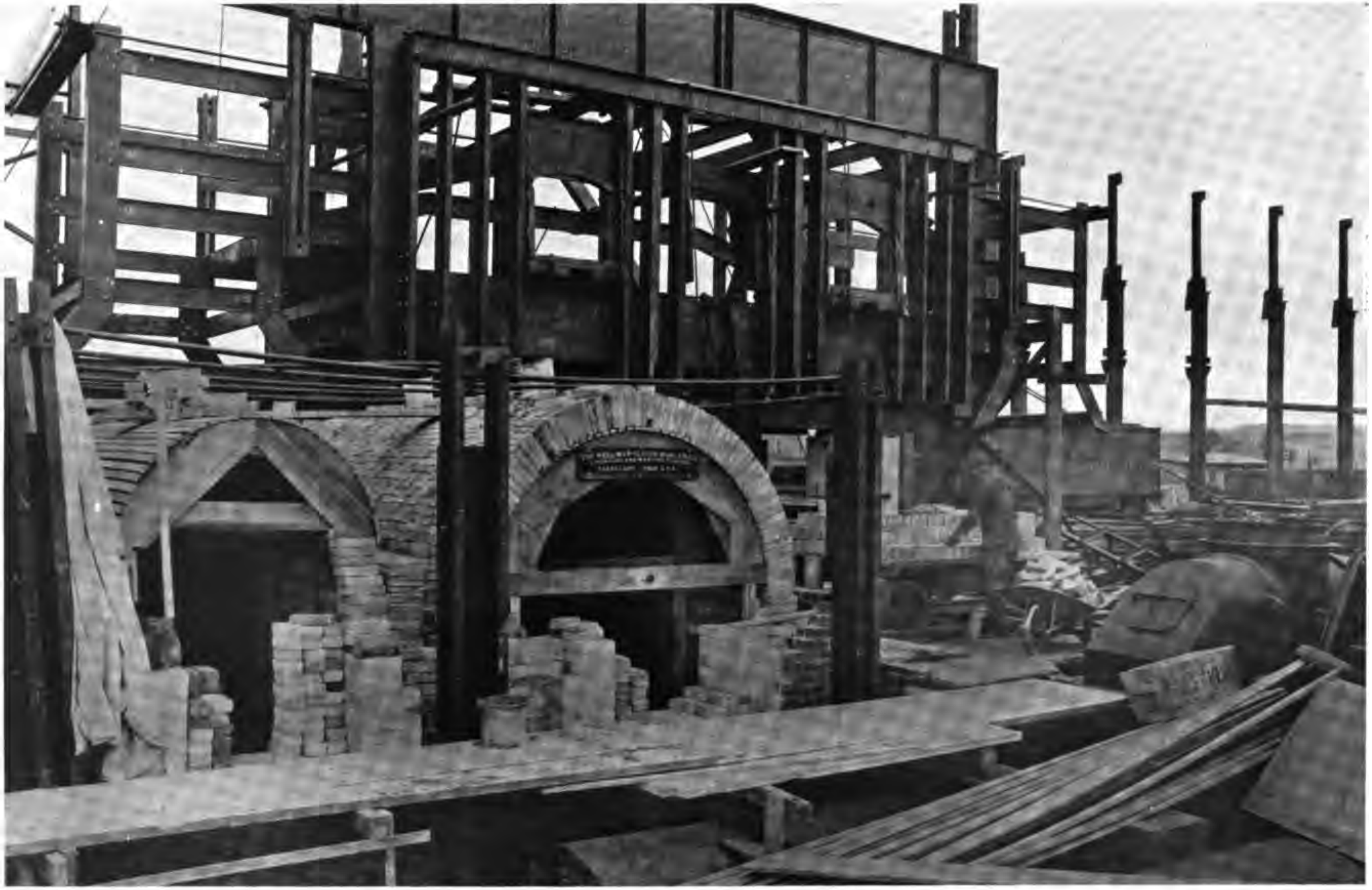


Figure 155—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Steel plate pan for furnace bottom in place. Cast steel door sills, jambs, and arch plates being set, regenerators showing centering for roof arches.

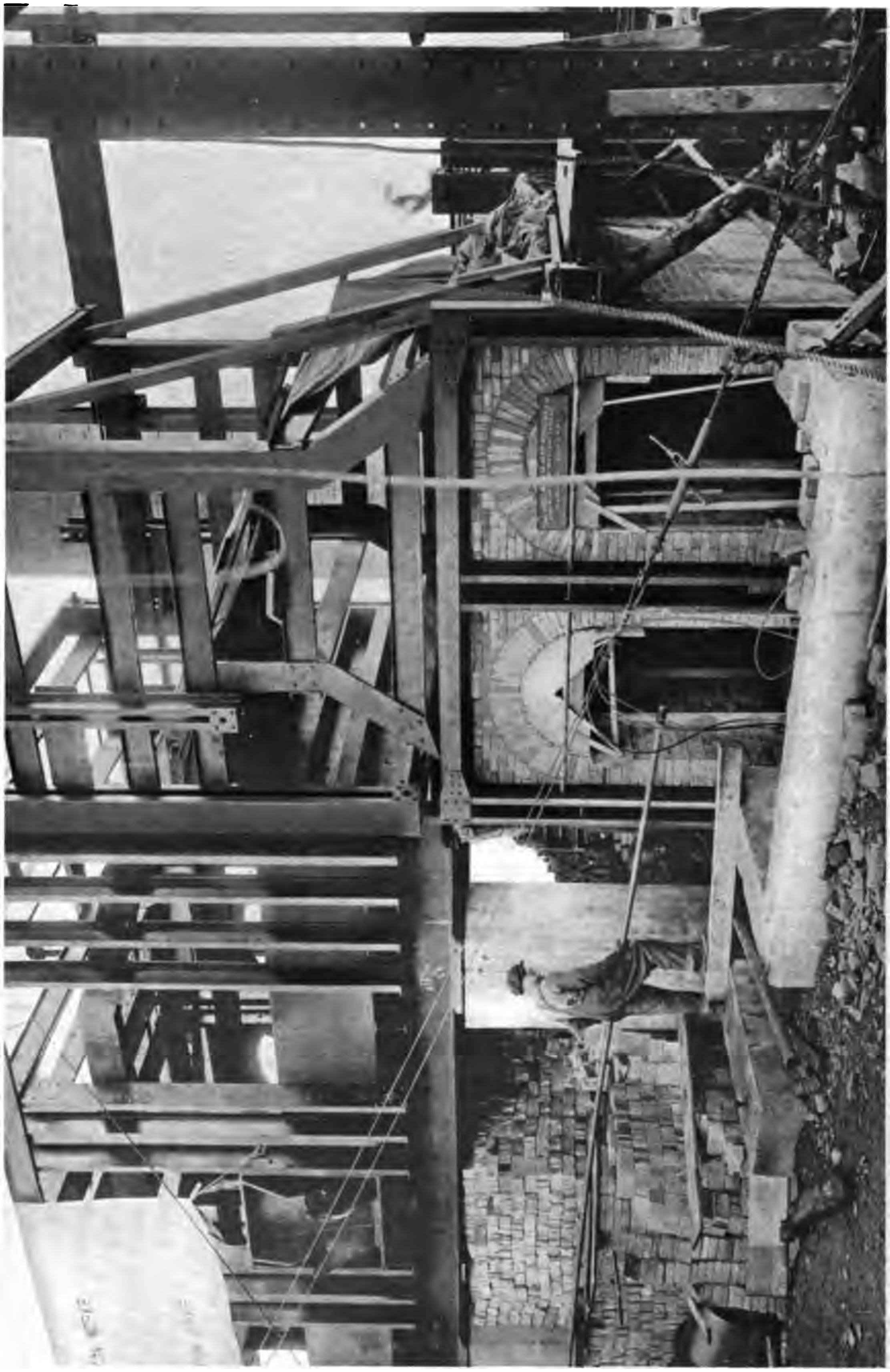


Figure 156—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Corner posts of uptakes are of cast steel. The heavy character of the steel work used in the construction is well brought out in these views.

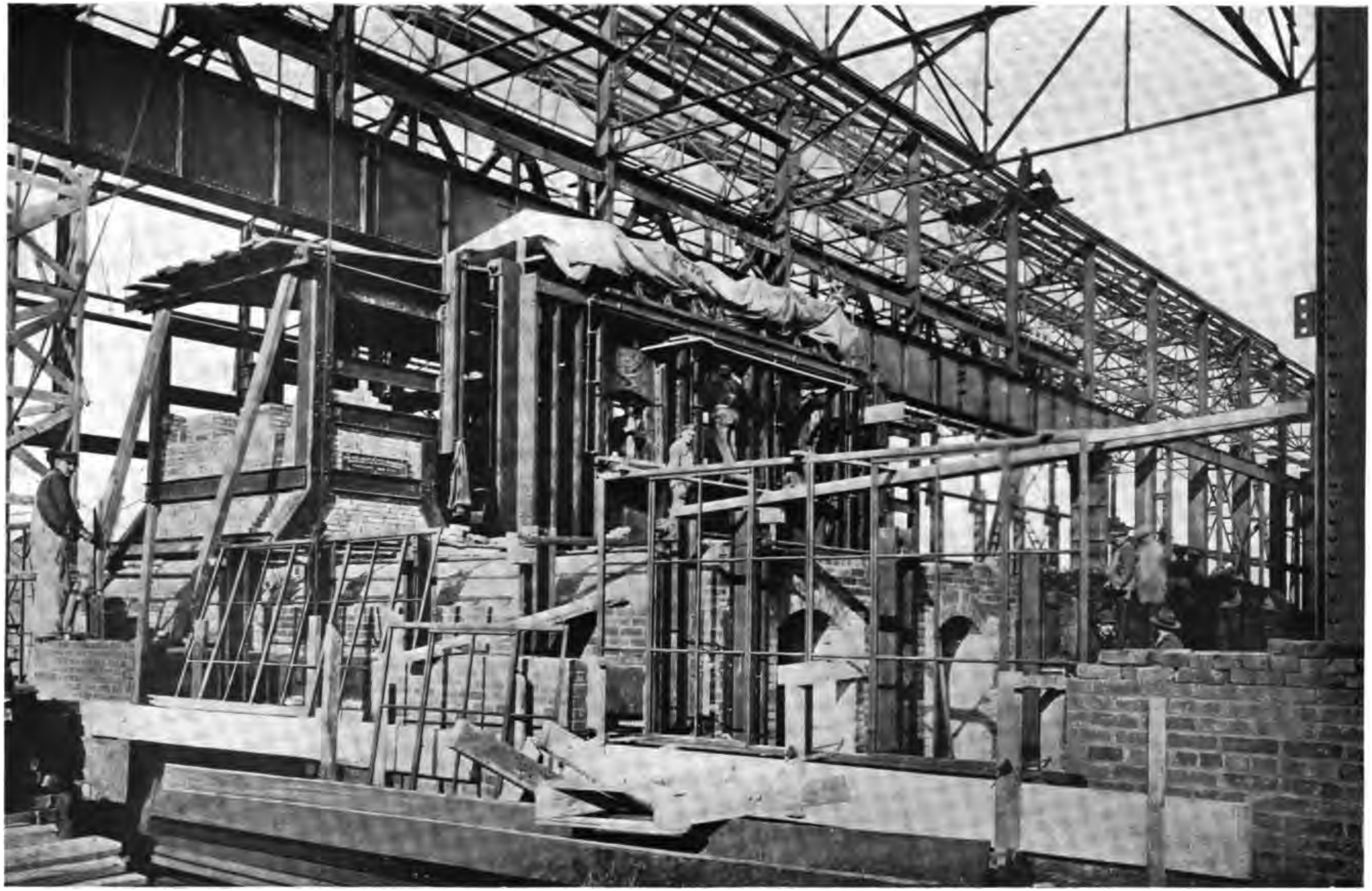


Figure 157—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

The brickwork of the uptakes rising into the port end binding. The expansion joints in the silica brick are made at each brick. When the full heat is reached the joints close up.

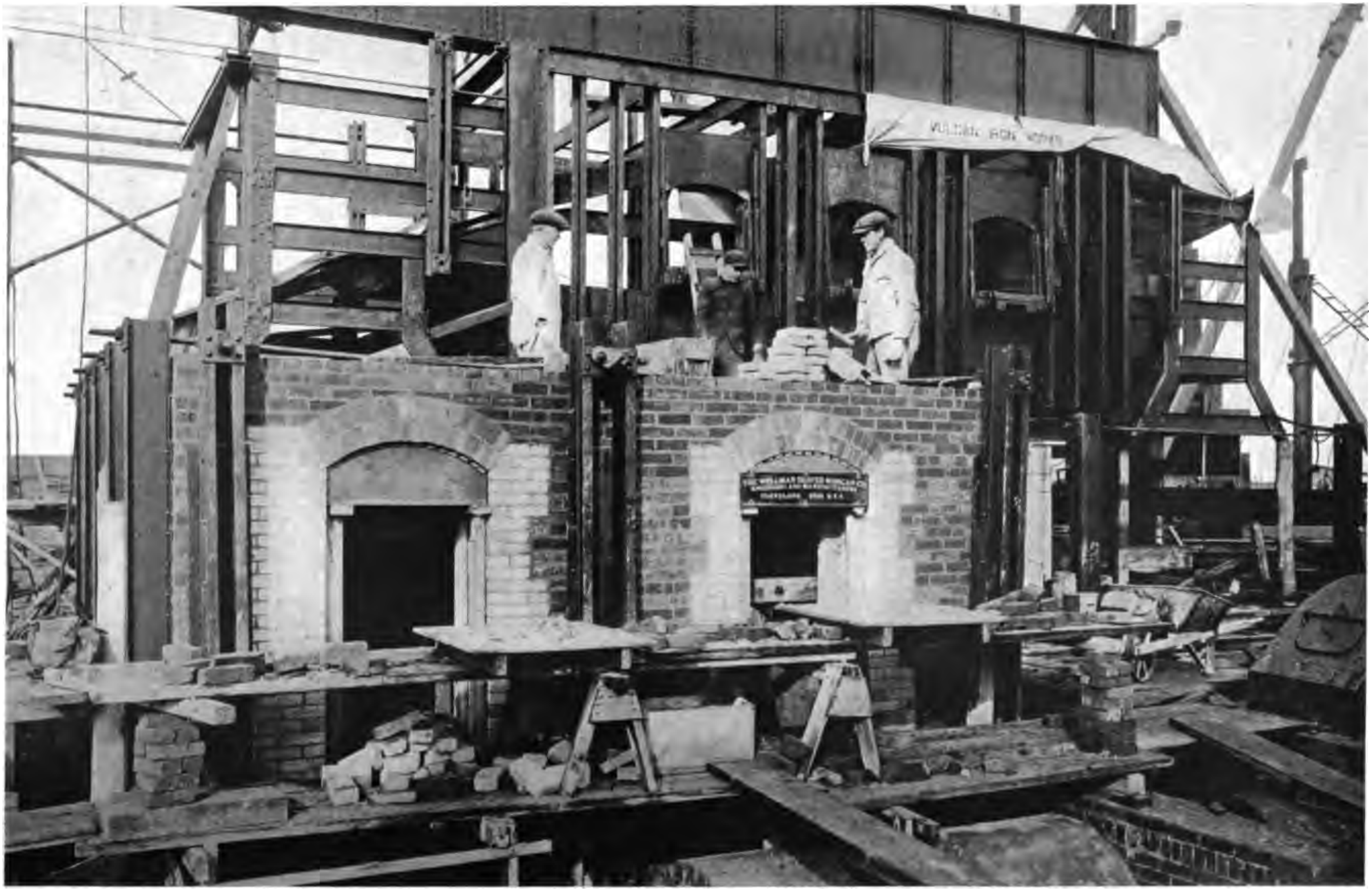


Figure 158—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

Completing the red brick work of the outside of the regenerators. The door openings are closed finally with a 9-inch silica brick wall.

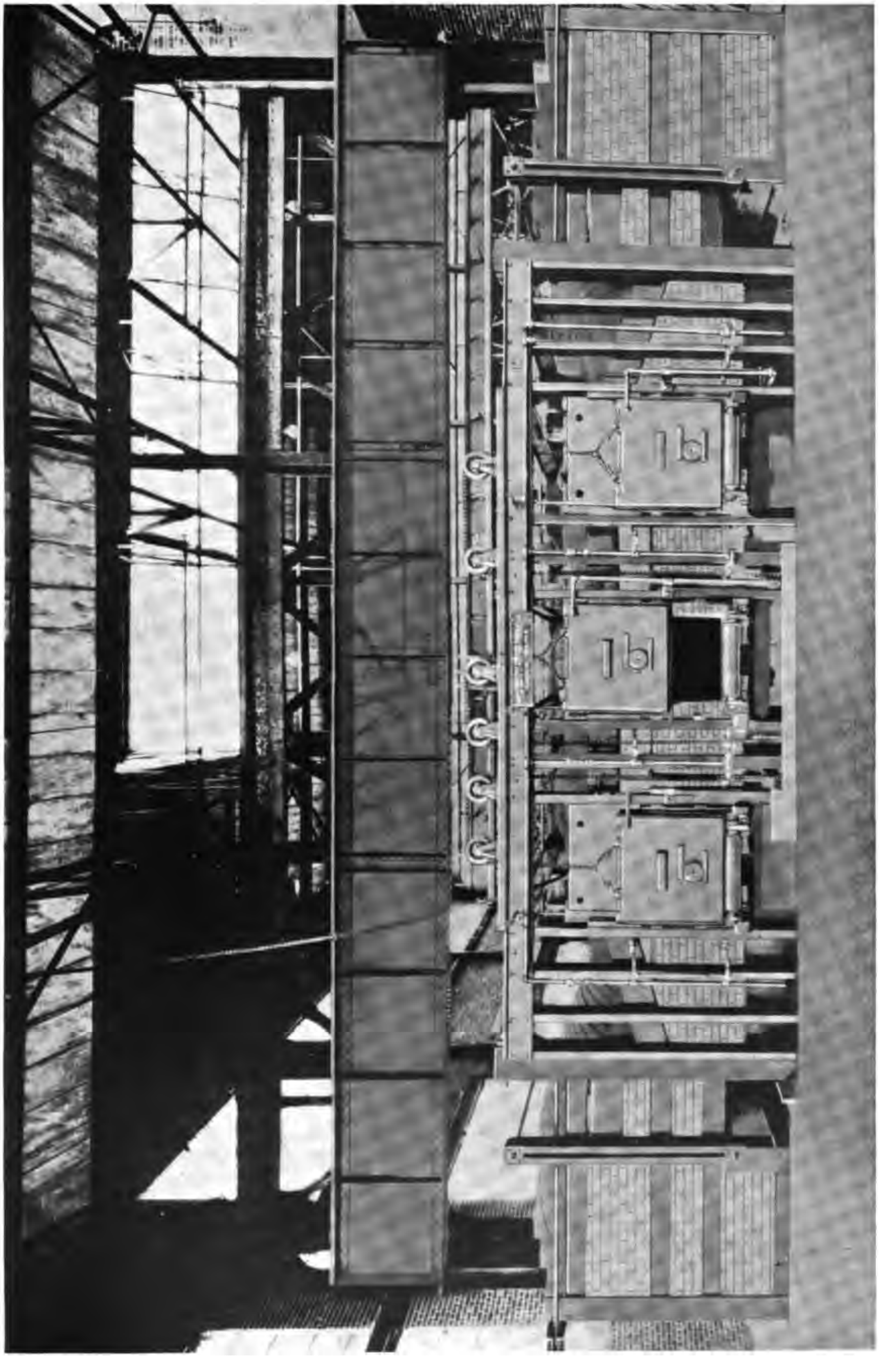


Figure 159—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

The completed furnace, charging side.

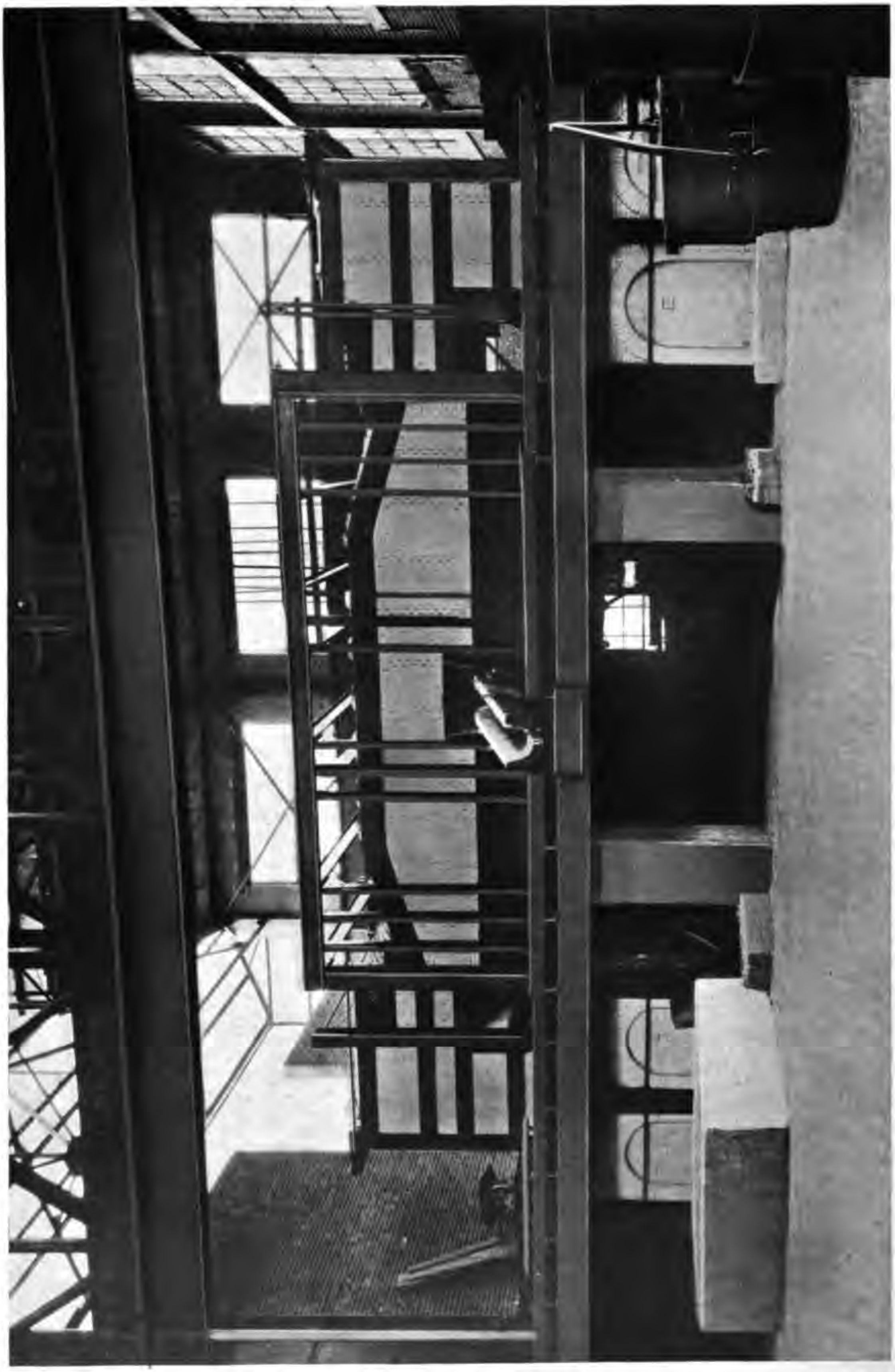


Figure 160—ERECTION VIEW 20-TON WELLMAN OPEN HEARTH FURNACE

The completed furnace, casting side.

CHAPTER XXV

Metallurgical Tables

For ready reference, tables are given of the more commonly used physical and chemical constants of materials used in open hearth metallurgy.

In this book the "lower" values of heats of combustion of hydro carbons are used, under the standard conditions of 32° F. and 30″ barometric pressure. The "higher" values are given in the tables for the sake of making quick comparisons with computations in which those data are used.

Table No. 73

Working Temperatures

	°C.	°F.
White gas at stack	300	572
Gas leaving producer	700	1292
Shale drain tile burning	871	1600
Shale paving brick	1000	1800
Composition earthenware	1015	1860
Shale sewer pipe	1016	1862
Fire clay paving brick	1048	1920
Fire clay sewer pipe, hottest	1048	1920
Glass pots working	1050	1922
Medium steel ready to roll	1050	1922
Ingot being rolled	1065	1950
Air leaving regenerators	1100	2012
Heating furnace	1150	2120
Gas leaving regenerators	1200	2192
Fire clay stoneware burning	1610	2922
Under a boiler	1257	2295
Crucible steel furnace	1300	2372
Glass pots refining	1325	2417
Tanks for casting glass	1325	2417
Open hearth furnace during boil	1500	2732
Blast furnace tapping	1600	2912
Medium hard steel at tapping	1600	2912
Cement rotary clinkering	1684	3000
Blast furnace at tuyeres	2000	3632

OPEN HEARTH TEMPERATURES

Gas Producer—Combustion zone	2800° F.
Gas leaving producer	1250° F.
Producer gas entering regenerator	1100° F.
Gas regenerator	2120° F.
Gas leaving regenerator	1940° F.
Air entering regenerator	100° F.
Air regenerator	2260° F.
Air leaving regenerator	2012° F.
Flame in furnace	3600° F.
Steel on leaving furnace	3012° F.
Gases on leaving furnace	2832° F.
Gases on leaving regenerator	1252° F.
Gases on entering stack	1200° F.
Average of steel on teeming ingot casting	2786° F.
Fusing of silica brick	3550° F.
1st quality clay fire-brick	3250° F.
2d quality clay fire-brick	2350° F.
3d quality clay fire-brick	2250° F.

The drop between the temperature of the combustion zone and the temperature of the gas leaving the producer is due to heat absorbed in the reactions and coal distillation by which gas is produced.

Table No. 74

The volume and weight of oxygen or air necessary to burn one pound of various elements, together with the products of combustion

Combustible	Required per lb. of combustible			Products of Combustion	Produced per Lb. of combustible		Nitrogen accompanying product of combustion when air is used	
	Oxygen Lbs.	Air						
		Lbs.	Cu. Ft.[1]		Lbs.	Cu. Ft.	Lbs.	Cu. Ft.
Hydrogen	8.00	34.64	429.1	Water[2]	9.00	174	26.64	340
Carbon (complete)	2.67	11.56	143.1	Carbon dioxide	3.67	29.9	8.89	114
Carbon (incomplete)	1.33	5.76	71.3	Carbon monoxide	2.33	29.8	4.43	56.7
Sulphur	1.00	4.33	53.6	Sulphur dioxide	2.00	11.2	3.33	42.5

[1] At 0° C. and 760 mm. of mercury pressure = 32° F. and 29.92 ins.

[2] Water considered uncondensed at 0° C. and 760 mm. in order to facilitate calculation of volume of products at various temperatures.

Table No. 75

The volume of oxygen and air necessary to burn one cubic foot of certain gases together with the products of combustion

Gas	Symbol	Required to burn 1 cu. ft. of gas		Produced per cubic foot of gas		
		Oxygen cubic feet	Air cubic feet	Water vapor cubic feet	Carbon dioxide cubic feet	Accompanying nitrogen when air is used cu. ft.
Hydrogen	H_2	0.5	2.41	1	0	1.91
Carbon monoxide	CO	0.5	2.41	0	1	1.91
Methane	CH_4	2.0	9.62	2	1	7.62
Ethane	C_2H_6	3.5	16.84	3	2	13.34
Propane	C_3H_8	5.0	24.05	4	3	19.05
Butane	C_4H_{10}	6.5	31.27	5	4	24.77
Pentane	C_5H_{12}	8.0	38.48	6	5	30.48
Hexane	C_6H_{14}	9.5	45.70	7	6	36.20
Ethylene	C_2H_4	3.0	14.43	2	2	11.43
Propylene	C_3H_6	4.5	21.64	3	3	17.14
Benzene	C_6H_6	7.5	36.08	3	6	28.58

Table No. 76

Heat carried away by Dry Chimney Gases per pound of Combustible*

PER CENT LOSS

	Temperature of Chimney Gases deg. Fahr.							
Pounds of air per pound of combustible.	300°	350°	400°	450°	500°	550°	600°	650°
12**	5.2	6.2	7.3	8.7	9.5	10.5	11.6	12.7
15	6.0	7.6	9.1	10.3	11.6	13.0	14.3	15.6
18	7.2	9.1	10.7	12.2	13.9	15.4	17.0	17.9
21	8.7	10.5	12.3	14.2	16.	17.8	19.5	21.
24	9.9	12.	14.	16.1	18.2	20.3	22.4	24.4
27	11.1	13.5	15.7	18.1	20.4	22.7	25.	27.4
30	12.4	14.9	17.4	20.	22.6	25.	27.8	30.4
33	13.5	16.3	19.2	22.	24.7	27.6	30.5	33.2
36	14.7	17.8	20.8	23.9	27.	30.	33.	36.6
39	15.9	19.2	22.5	25.8	29.2	32.4	35.7	39.0
42	17.1	20.6	24.7	27.7	31.3	34.8	39.4	42.0

*Gebhardt—Steam Power Plant Engineering.

**Theoretical Requirement—Calorific Value of Fuel assumed to be 14,500 Btu. per pound.

Table No. 77

Loss of Heat due to Incomplete Combustion of Carbon to Carbon Monoxide*

PER CENT LOSS

	Per cent of Carbon Dioxide in the flue gas by volume					
	6	8	10	12	14	16
Per cent of carbon monoxide in the flue gases by volume. 0.2	2.2	1.7	1.3	1.1	1.0	0.8
0.4	4.3	3.3	2.6	2.2	1.9	1.7
0.6	6.3	4.8	3.9	3.2	2.8	2.5
0.8	8.1	6.3	5.1	4.3	3.7	3.4
1.0	10.2	7.7	6.3	5.3	4.6	4.1
1.2	11.5	9.0	7.4	6.3	5.4	4.8
1.4	13.1	10.3	8.5	7.2	6.3	5.6
1.6	14.3	11.5	9.5	8.1	7.1	6.3
1.8	16.0	12.7	10.5	9.0	7.8	7.0
2.0	17.2	13.8	11.5	9.9	8.6	7.7

Heating Value of Carbon taken as 14,500 Btu. per pound.
*Gebhardt—Steam Power Plant Engineering.

Table No. 78

Combustion Data

General Efficiencies of Furnaces*

Crucible Steel Melting Wind Furnace	2 — 3%
Reverberatory Furnace	10 — 15
Regenerative Open Hearth Furnace	10 — 20
Shaft Furnace (Direct Contact)	30 — 50
Steam Boilers and Hot Blast Stoves	50 — 75
Large Electric Furnaces	60 — 85

* Richards—Metallurgical Calculations.

Table No. 79

Composition of Air

	By weight	By volume
Oxygen	23.1%	20.8
Nitrogen	76.9	79.2
	100.0	100.0

Table No. 80

Metric Equivalents

1 —Kilogram = 2.2046 lbs. = 35.273 oz. Av.
1 —Cu. Meter = 35.314 cubic feet.

Table No. 81

Flow of Gases

P = loss of pressure in conduit by skin friction in lbs. per sq. ft.
F = Kutter's constant = 0.005 to 0.007. For brickwork 0.007.
V = velocity in feet per second of gas or air.
S = area in sq. ft. of surface in contact with gas or air.
D = density of gas or air = weight in pounds per cu. ft.
g = 32. Usually n = 2.0.

$$P = F \text{ x } D \text{ x } S \frac{V^n}{2g} = F \text{ x } D \text{ x } S \frac{V^2}{64}$$

V = velocity—second feet.
Q = quantity—second cubic feet.
A = cross sectional area in sq. ft. of conduit.
C = coefficient of contraction—found by experiment.
D = weight of gas per cu. ft.
P = head pressure—lbs. per sq. ft.
H = head = P ÷ D in feet.
Q = C x A x V.

Table No. 82

Velocity of Gases in Open Hearth Furnaces

Gas or air through the reversing valve	11.5
Gas entering the regenerator	9.8 second feet
(Average) through the regenerator chamber	3.3 second feet
(Average) through the regenerator checkers	6.5 second feet
Gas or air through the open space above the checkers	1.6 second feet
Gas issuing from port openings	26.5 second feet
Air issuing from port openings	28.0 second feet
Gases—across the hearth	6.5 second feet

Table No. 83

Time of Contact of Gases

In regenerators—gas—not less than	4.0 seconds
In checkerwork—gas—not less than	3.0 seconds
In regenerators—air—not less than	5.0 seconds
In checkerwork—air—not less than	3.0 seconds
In furnace laboratory—over the metal not less than	2.0 seconds

Table No. 84

Flow of Steam in Pipe

To determine the size pipe to pass through it a given quantity of steam, assuming a velocity of 5000 feet per minute as good practice.

A = pounds of steam per hour.
V = 5000 feet per minute.
B = Volume in cu. ft. of 1 lb. of steam at given pressure.
1728 = cu. in. in foot.
60 = minutes in hour.
12 = inches in foot.
X = area of pipe sought in square inches.

$$X = \frac{A \times B \times 1728}{60 \times 5000 \times 12} = \frac{A \times B}{2083}$$

Table No. 85

Heat Values of Fuels

For estimating purposes in figuring comparisons between producer gas, natural gas, and oil, the following heat values should be used:

Producer Gas....	150 Btu. per cu. ft.
Natural Gas.....	1000 Btu. per cu. ft.
Oil..............	125000 Btu. per gal.

One pound of coal will make approximately 60 cu. ft. of producer gas.

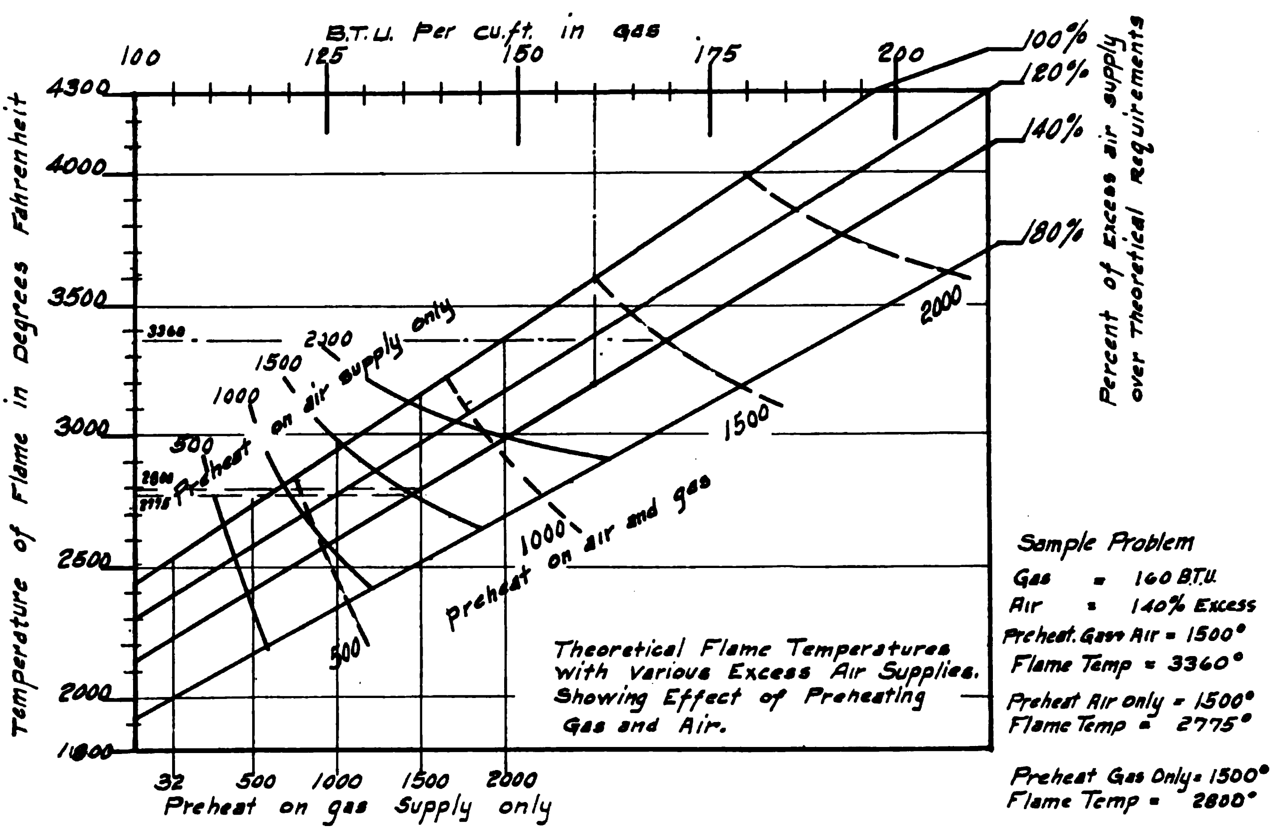


Figure 161—DIAGRAM OF FLAME TEMPERATURES

Table No. 86

Heat of Combustion

	FUEL.	SYMBOL	W'T PER CU. FOOT 62°	Sp Ht GASES AT C_p	B.T.U. PER POUND		B.T.U. PER CUBIC FOOT.			
					HIGH	LOW	HIGH	LOW	HIGH	LOW
							32° FAHR.		62° FAHR.	
SOLID FUELS	ANTHRACITE-SCHUYLKILL		55 To		13682	13616				
	" COLORADO		65 LBS		12616	12200				
	ALASKA				15000	14070				
	BITUMINOUS-PITTSBURGH				14370	13950				
	" W. VA.				15260	14870				
	" " "		50 To		14670	14000				
	" OHIO		55		13510	13140				
	" INDIANA		LBS.		12510	12080				
	" ILLINOIS				13000	12730				
	" OKLAHOMA				13300	13050				
	" COLORADO				12970	12620				
	" WYOMING				12440	12090				
	LIGNITE-DRY [H_2O RUNS UP TO 35%]				11070					
	PEAT " "	" " -	22%		10290					
	CARBON TO CO	C		.241	4374	4374				
	- " " CO_2	C	.11663	.200	14544	14544				
GASES	" MONOXIDE TO "	CO	.07357	.243	4325	4325	338	338	319	319
	AIR	N. 77% O. 23	.0762	.2375						
	METHANE [MARSH GAS	CH_4	.04216	.593	23646	21463	1066	959	1005	905
	ACETYLENE	C_2H_2	.07613	.346	21400	20727	1595	1578	1503	1487
	ETHYLENE OLEFIANT GAS	C_2H_4	.07360	.404	21300	20053	1700	1595	1602	1503
	ETHANE	C_2H_6	.08394	.464	22027	20280	1845	1700	1738	1602
	BENZENE	C_6H_6	.02052	.299	17312	16637	3798		3579	
	HYDROGEN	H_2	.00530	3.409	60626	51892	341	292	330	275
	OXYGEN	O_2	.0841	.217						
	NITROGEN	N_2	.07380	.244						
	BLAST F'CE GAS		.0783	.253	1115	1110	93	92	87	87
	BENCH RETORT GAS		.0319	1.853	18970	17023	604	543	569	512
	COKE OVEN "		.069	1.935	1810	1743	132	127	125	120
	BLUE WATER "		.043	1.766	6210	5700	313	288	296	271
	CARBURET'D " "		.073	1.615	7312	6692	568	519	535	490
	OIL "		.146	1.444	5820	4274	901	817	850	770
	PRODUCER-ANTHRACITE		.0613	.656	2312	2161	153	143	144	135
	" BITUMINOUS		.067	.655	2315	2165	164	154	155	145
	" COKE GAS		.0707	.526	1810	1710	135	127	127	120
	" LIGNITE "		.067	.734	2162	2006	153	142	144	133
	" PEAT "		.065	.832	2397	2216	165	153	155	144
	" TANBARK "		.072	.532	1820	1685	135	121	127	114
	NATURAL GAS-PA.		.0425	.632	23120	20696	1197	1106	1128	1042
	" " OHIO				22170	19926	1153	1035	1084	975
	" " INDIANA				23120	20675	1200	1073	1130	1011
	" " KANSAS				23458	21301	1046	950	986	895
LIQUIDS	ALCOHOL-ETHYL	C_2H_6O	GALLON 6.83	505	11880	10620	91.3% ALCOHOL 8.7% WATER			°F.
	" METHYL	CH_4O		.590	9550	8340	ABSOLUTE TEMP. OF 32°			=491.63
	BENZOL		7.84	.340	18000	17300		"	" " 62	=521.63
	GASOLENE	GR. .87	5.44	.533	21200	19990	TO CONVERT WEIGHTS &			
	KEROSENE 120°	" .49	6.80	.475	21900	20340	HEATS OF COMBUSTION OF			
	CRUDE PENNA.		AVE.	.511	20949	19735	GASES FROM		62° TO	32°
	PETR- CALIF.		7.3		19920	18810	MULTIPLY VALUES AT 62°			
	OLEUM OHIO		SP. GR		20750	19550	BY	1.0611		
	TEXAS		0.82		18980	18025	TO CHANGE FROM 32° TO 62°			
	OKLAHOMA				20780	19685	MULTIPLY VALUES AT 32°			
	COAL TAR				19710	16500	BY 0.94241			
	OIL "				16500	16000.				

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Table No. 87

Characteristics of Gases

Based on Standard Conditions of 62° F. & 30″ Mercury

1	COLUMN	1	2	3	4		5	6	
2	GAS.	SYMBOL	SPECIFIC GRAVITY	WT. OF ONE CU FT. LBS.	HEAT OF COMBUSTION B.T.U. PER CU. FT.		VOLUME OF O_2 NEEDED FOR COMBUSTION.	PRODUCTS OF COMBUSTION	
					GROSS.	NET		CO_2	H_2O
3	AIR		1.0000	.07634					
4	CARBON DIOXIDE	CO_2	1.5288	.11671				1.0	
5	ETHYLENE	C_2H_4	.9752	.07445	1595	1495	3.0	2.0	2.0
6	OXYGEN	O_2	1.1052	.08437					
7	CARBON MONOXIDE	CO	.9648	.07635	322	322	.5	1.0	
8	METHANE	CH_4	.5544	.04232	1009	909	2.0	1.0	2.0
9	HYDROGEN	H_2	.0695	.005306	324	274	.5		1.0
10	NITROGEN	N_2	.9651	.07368					
11	ETHANE	C_2H_6	1.0449	.07977	1773	1623	3.5	2.0	3.0
12	BENZENE	C_6H_6	2.7708	.21152	3902	3752	7.5	6.0	3.0
13	SULPHUR DIOXIDE							SO_2	
14	HYDROGEN SULPHIDE	H_2S	1.1906	.09089	656	606	1.5	1.0	1.0
15	WATER VAPOR	H_2O	.6221	.04749					1.0
16	CYANOGEN	C_2N_2	1.806	.1379					

From "Methods for the Technical Sampling and Analysis of Gases"
UNITED STATES STEEL CORPORATION
J. M. Camp, Chairman—Chemist's Committee
Table "A"

Table No. 88

Heat of Chemical Combination—Metals

Richards-Metallurgical Calculations

SUBSTANCE	HEAT OF OXIDATION					
	CALORIES PER KILOGRAM			B.T.U. PER POUND		
	METAL	OXYGEN	OXIDE	METAL	OXYGEN	OXIDE
Al_2O_3	7270	8179	3849	12986	14722	6928
CaO	3288	8219	2348	5918	14794	4226
FeO	1173	4106	913	2114	7390	1643
Fe_2O_3	1746	4075	1223	2643	7335	2201
Fe_3O_4	1612	4231	1167	2902	7616	2100
MgO	5975	8963	3585	10755	16133	6453
MnO	1653	5681	1280	2975	10225	2304
MnO_2	2278	3916	1440	4100	7045	2592
Mn_3O_4	1988	5125	1434	3578	9225	2581
P_2O_5	5895	4566	2572	10611	8219	4630
SiO_2	7000	6125	3267	12600	11025	5880
TiO_2	4550	6825	2730	8190	12285	4914
	HEAT OF FORMING CARBONATES.					
	FROM THE OXIDES					
	OXIDE	CO_2	CARBONATE	OXIDE	CO_2	CARBONATE
CaO, CO_2	806	1026	451	1451	1847	812
FeO, CO_2	346	566	215	623	1019	387
MgO, CO_2	733	666	349	1320	1200	628
MnO, CO_2	313	505	193	563	909	347
	SILICATES FROM THE OXIDES					
	OXIDE	SiO_2	SILICATE	OXIDE		
$Al_2O_3\,SiO_2$	−118	−200	−74	−202	−360	−133
$Al_2O_3\,2SiO_2$	146	124	67	263	223	120
$CaO\,SiO_2$	319	297	154	574	535	277
$2CaO\,SiO_2$	253	472	165	455	805	297
$3CaO\,SiO_2$	170	476	125	306	757	225
$3CaO\,Al_2O_3\,2SiO_2$	CaO 288	303	113	518	545	203
	Al_2O_3 475			855		
$FeO\,SiO_2$	129	155	70	232	279	126
$MnO\,SiO_2$	76	90	41	137	162	74
FeO 71%	~~153~~	~~376~~	~~109~~	~~295~~	~~677~~	~~196~~
SiO_2 29%						
FeO 57.6%	FeO 243			437		
CaO 12.0%	CaO 1167	461	140	2100	830	252
SiO_2 30.4%	SiO_2 201			362		

SUBSTANCE.	SILICATES FORMED FROM OXIDES (CONTINUED)					
	CALORIES PER KILOGRAM			B.T.U. PER POUND		
	OXIDE	SiO_2	SILICATE	OXIDE	SiO_2	SILICATE
FeO 4.03%	FeO 479			862		
CaO 28.0%	CaO 689	461	140	1440	830	151
SiO_2 31.7%	SiO_2 283			509		
FeO 39.7%	FeO 335			603		
CaO 15.2%	CaO 875	395	133	1575	675	239
Al_2O_3 9.2%	BASES 206			370		
SiO_2 35.5%						
	SILICATES FROM THE METALS					
$FeSiO_3$	4839		2053	8710		3695
$MnSiO_3$	5315		2231	9567		4016
	FORMATION OF CARBIDES					
	METAL	CARBON	CARBIDE	METAL	CARBON	CARBIDE
CaC_2	181	302	113	326	544	203
Fe_3C	50	705	47	90	1269	85
Mn_3C	60	825	57	108	1485	103
	FORMATION OF PHOSPHIDES					
	METAL	PHOS.	PHOSPHIDE	METAL	PHOS	PHOSPHIDE
FeP	0	0	0	0	0	0
Mn_3P_2	430	1144	312	774	2059	562
	FORMATION OF PHOSPHATES					
$Ca_3P_2O_8$	7660	FROM THE METAL		13788		
$Mn_3P_2O_8$	4490	" " "		8046		
	FROM OXIDE & P_2O_5					
$3CaO\,P_2O_5$	949	1123	514	1708	2021	925
$3MgO\,P_2O_5$	959	811	429	1726	1460	772
$3MnO\,P_2O_5$	467	701	280	850	1262	504
	FORMATION OF SULPHIDES					
CaS	2358	2947	1310	4244	5305	2358
MgS	3308	2481	1418	5054	4466	2552
MnS	829	1425	524	1492	2565	943
FeS	428	750	273	770	1350	491
SiS	1429	625	435	2572	1125	783

Table No. 89

Specific Heat = S_m $Q = S_m t$

Substance	Symbol	Temperature °C	Temperature °F	Specific Heat—Weight: Cal. per Kilogram / Btu. per Lb.	Specific Heat—Volume: Cal. per Cu. Meter / Btu. per Cu. Foot	Temperature Fusion (Deg. Centi.)	Temperature Boiling (Deg. Centi.)	Heat = Q As a Solid (Calories per Kilo.)	Heat = Q Of Fusion (Calories per Kilo.)	Heat = Q Total Q (Calories per Kilo.)	Remarks
Carbon	C	To 250		0.1567+0.00036t							Amphorous and Graphitic
	C	250 to 1000		0.2142+0.000166t							
	C	At 1000		0.528 Violle; 0.546 Weber				380			
	C	Over 1000		0.443+0.000,0425t−$\frac{106.5}{t}$			3700	2114	6254		
Carbon Monoxide	CO	To 2000		0.2405+0.000,0214t Cals.	0.303 +0.000,027t Cals.						
	CO		To 3600	0.2405+0.000,0119t Btu.	0.0189+0.000,0009t Btu.						
	CO	2000 to 4000		0.2044+0.000,057t Cals.	0.2575+0.000,072t Cals.						
	CO		3600 to 7200	0.2044+0.000,032t Btu.	0.0161+0.000,0025t Btu.						
Carbon Dioxide	CO_2	To 2050		0.19+0.000,11t Cals.	0.37 +0.000,22t Cals.						
	CO_2		To 3700	0.19+0.000,06t Btu.	0.023+0.000,008t Btu.						
	CO_2	2000 to 4000		0.42+0.000,034t Cals.	0 815+0.000,0675t Cals.						
	CO_2		3600 to 7200	0.41+0.000,019t Btu.	0.051+0.000,0023t. Btu.						
Calcium Carbonate	$CaCO_3$	20-100		0.2086							Calcite
Dolomite	$CaCO_3$	20-100		0.2179							CaMg $(CO_3)_2$
Calcium Oxide	CaO	24-100		0.1743							
	CaO	0°-t		0.1715+0.000,07t							
Chromium		To 600		0.1039+0.000,000,08t_2		1489		352	71	423	
Chromium Oxide	Cr_2O_3	10-99		0.1796							
Ethyelyne	C_2H_4			0.46+0.0003t							
Hydrogen	H	To 2000		3.37+0.000,3t Cals.	0.303 +0.000,027t Cals.						
	H		To 3600	3.37+0.000,17t Btu.	0.0189+0.000,0009t Btu.						
	H	2000-4000		2.75+0.000,8t Cals.	0.2575+0.000,072t Cals.						
	H		3600-7200	2.75+0.000,44t Btu.	0.0161+0.000,0025t Btu.						
Iron	Fe	To 660°		0.11012+0.000,025t Cal.							
	Fe	At 660						96.1		96.1	
	Fe	At 750						125.6		125.6	
	Fe	Over 750		0.1675 Constant Cals.							
	Fe	750-1500				1535		255	66	322	0.1675t—51 Cals.
	Fe	1535		0.20 Cals.			1535			322	Liquid
Iron Oxide	Fe_2O_3	0° to t°C		0.1456+0.000,188t Cals.							
	Fe_3O_4	0° to t°C		0.1447+0.000,188t Cals.							
Iron Sulphide	FeS	17-98		0.1357 Calories							
Iron Carbonate	$FeCO_3$	9-98		0.1938 Calories							
Magnesite	Mg;Fe_2 $(CO_3)_9$	17-100		0.227 Calories							

Table No. 89 (Continued)

Specific Heat

		Temperature		Specific Heat—Weight	Specific Heat—Volume	Temperature		Heat = Q			
Substance	Symbol	°C	°F	Cal. per Kilogram	Cal. per Cu. Meter	Fusion	Boiling	As a Solid	Of Fusion	Total Q	Remarks
				Btu. per Lb.	Btu. per Cu. Foot	Deg. Centi.		Calories per Kilo.			
Manganese	Mn	0°-t		0.1088+0.000,103t Cals.		1900				572	
	Mn	1900		0.357 Cals.							
Manganese Oxide	MnO	13°-98°		0.157 Cals.							
Manganese Sulphide	MnS	10-100		0.1392 Cals.							
Methane	CH_4	0-t		0.38+0.000,22t							
Nickel	Ni	0 to 230		0.10836+0.000.02233t		1450		221	68	289	Sm Liquid 0.197
	Ni	440 to 1050		0.099 +0.000,03375t							
Nitrogen	N	to 2000		0.2405+0.000 0214t Cals.	0.303 +0.000,027t Cals.						
	N		To 3600	0.2405+0.000,0119t Btu.	0.0189+0.000,0009t Btu.						
	N	2000-4000		0.2044+0.000,057t Cals.	0.2575+0.000,072t Cals.						
	N		3600 to 7200	0.2044+0.000,032t Btu.	0.0161+0.000,0025t Btu.						
Oxygen	O	To 2000		0.2104+0.000,0187tCals.	0.303 +0.000,027t Cal.						
	O		To 3600	0.2104+0.000,0104t Btu.	0.0189+0.000,0009t Btu.						
	O	2000-4000.		0.1788+0.000,05t Cals.	0.2575+0.000,072t Cals.						
	O		3600-7200	0.1788+0.000,03t Btu.	0.0161+0.000,0025t Btu.						
Silicon		To 234		0.17+0.000,07t Cals.		1430		386	108	494	S_m Liquid = 0.37
Slag					According to % of SiO_2, CaO, Al O_3					347-530	
Tungsten	W	To 423		0.033 +0.000,011t Cals.		3350		234	40	274	
Titanium	Ti	0° to t°		0.0978+0.000,0035t Cals.		800		187	90	277	S. Liquid = 0.2084
Vanadium	V	0° to t°		0.105 +0.000,03t Cals.		1710		267	82	349	S. Liquid = 0.208
Molybdenum		0° to t°		0.0655+0.000,02t Cals.		2500		289	61	350	S. Liquid = 0.165
Water	H_2O	0°-100°		1.0+0.000,15t							S at 15° = 1.0045
Water, Gas or Vapor	H_2O	To 2000		0.42+0.000,185t Cals.	0.34 +0.000,15t Cals.						
			To 3600	0.42+0.000,103t Btu.	0.021+0.000,005t Btu.						
		2000 to 4000		0.59+0.000,21t Cals.	0.48 +0.000,17t Cals.						
			3600 to 7200	0.59+0.000,12t Btu.	0.03 +0.000,006t Btu.						

Note: $Q = 606.5 + 0.305t$ = Cals. per Kilo of H_2O Liquid at O°C into Steam at Max. P. at Temp. t.: In Metallurgy find heat to convert into H_2O into vapor at 0° = 606.5 Cals. then use Eq. $S_m = 0.34 + 0.00015t$ considering the vapor as true gas.

Temperatures for Calories are in Centigrade, and for Btu. in Fahr. Degrees.

This table embodies values from "Metallurgical Calculations," by J. W. Richards, Ph.D., but recast in tabular form.

Table No. 90

International Atomic and Molecular Weights of 1913

Oxygen = 16

Chemical Name	Usual Name	Symbol	Atomic Weight	Molecular Weight
Aluminum	Aluminum	Al	27.1	
Aluminum Oxide	Clay	Al_2O_3		75.1
Aluminum Carbide	Carborundum	Al_4C_3		156.4
Aluminum Fluoride		AlF_3		84.1
Aluminum Sulphide		Al_2S_3		150.41
Aluminum Silicate		Al_2SiO_5		135.4
Calcium	Calcium	Ca	40.07	
Calcium Carbide	Calcium Carbide	CaC_2		64.07
Calcium Carbonate	Limestone	$CaCO_3$		100.07
Calcium Fluoride	Fluorspar	CaF_2		59.07
Calcium Phosphate		$Ca_3P_2O_8$		326.41
Calcium Silicate		$CaSiO_3$		116.37
Calcium Oxide	Lime	CaO		56.07
Carbon	Carbon	C	12	
Carbon Dioxide		CO_2		44.0
Carbon Monoxide		CO		28.0
Chromium	Chromium	CR	52	
Chromium Oxide	Chrome Ore	CrO_3		100.0
Chromic Oxide	Chrome Ore	Cr_2O_3		152.0
Chlorine	Chlorine	Cl	35.46	
Ethane		C_2H_6		30.048
Ethylene	Olefiant Gas	C_2H_4		28.032
Fluorine	Fluorine	F	19.0	
Hydrogen	Hydrogen	H	1.008	
Hydrogen Oxide	Water	H_2O		18.016
Iron	Iron	Fe	55.84	
Iron Carbide		Fe_3C		179.52
Iron Carbonate	Siderite	$FeCO_3$		115.84
Iron Fluoride		FeF_2		93.84
Iron Oxide (Ferrous)	Protoxide of Iron	FeO		71.86
Iron Oxide (Ferric)	Hematite	Fe_2O_3		159.68
Iron Magnetic Oxide		Fe_3O_4		231.52
Iron Phosphide		FeP		94.94
Iron Sulphide		FeS		87.91
Iron Silicate	Slag	$FeSiO_3$		132.14
Magnesium	Magnesium	Mg	24.32	
Magnesium Carbonate	Magnesian Limestone	$MgCO_3$		84.32
Magnesium & Ca.carbonate	Dolomite	$MgCO_3CaCO_3$		184.39
Magnesium Oxide		MgO		40.32
Magnesium Phosphate		Mg_3PO_8		191.42
Magnesium Silicate		$MgSiO_3$		100.62
Magnesium Sulphide		MgS		56.39
Manganese		Mn	54.93	
Manganese Carbide		Mn_3C		176.79
Manganese Carbonate		$MnCO_3$		114.93
Manganese Oxide (Manganous)		MnO		70.93
Manganese Oxide (Manganic)	Sesquioxide	Mn_2O_3		157.86

Table No. 90 (Continued)

International Atomic and Molecular Weights of 1913

Oxygen = 16

Chemical Name	Usual Name	Symbol	Atomic Weight	Molecular Weight
Manganese Oxide		Mn_3O_4		228.79
Manganese Phosphide		Mn_3P_2		242.99
Manganese Phosphate		$Mn_3P_2O_8$		370.99
Manganese Silicate		$MnSiO_3$		121.23
Manganese Sulphide		MnS		87.00
Methane	Marsh Gas	CH_4		16.032
Molybdenum		Mo	96.0	
Nickel		Ni	58.68	
Nitrogen		N	14.01	
Oxygen		O	16.00	
Phosphorus		P	39.10	
Phosphoric Acid		P_2O_5		158.2
Silicon		Si	28.3	
Silicon Carbide		SiC		40.3
Silicon Fluoride		SiF_4		104.3
Silicon Oxide	Quartz—Sand	SiO_2		44.3
Sulphur	Brimstone	S	32.07	
Sulphur Dioxide		SO_2		48.07
Sulphurous Acid		SO_3		80.07
Titanium		Ti	48.1	
Titanium Oxide		TiO_2		80.1
Tungsten		W	184.0	
Uranium		U	238.5	
Vanadium			51.0	
Slag	Fe 71%, SiO_2 29%			43.49
Slag	FeO 57.6%, CaO 12%, SiO_2 30.4%			61.59
Slag	FeO 40.3%, CaO 28%, SiO_2 31.7%			58.70
Slag	Al_2O_3 9.2%, FeO 39.7%, CaO 15.2%, SiO_2 35.5%			59.69

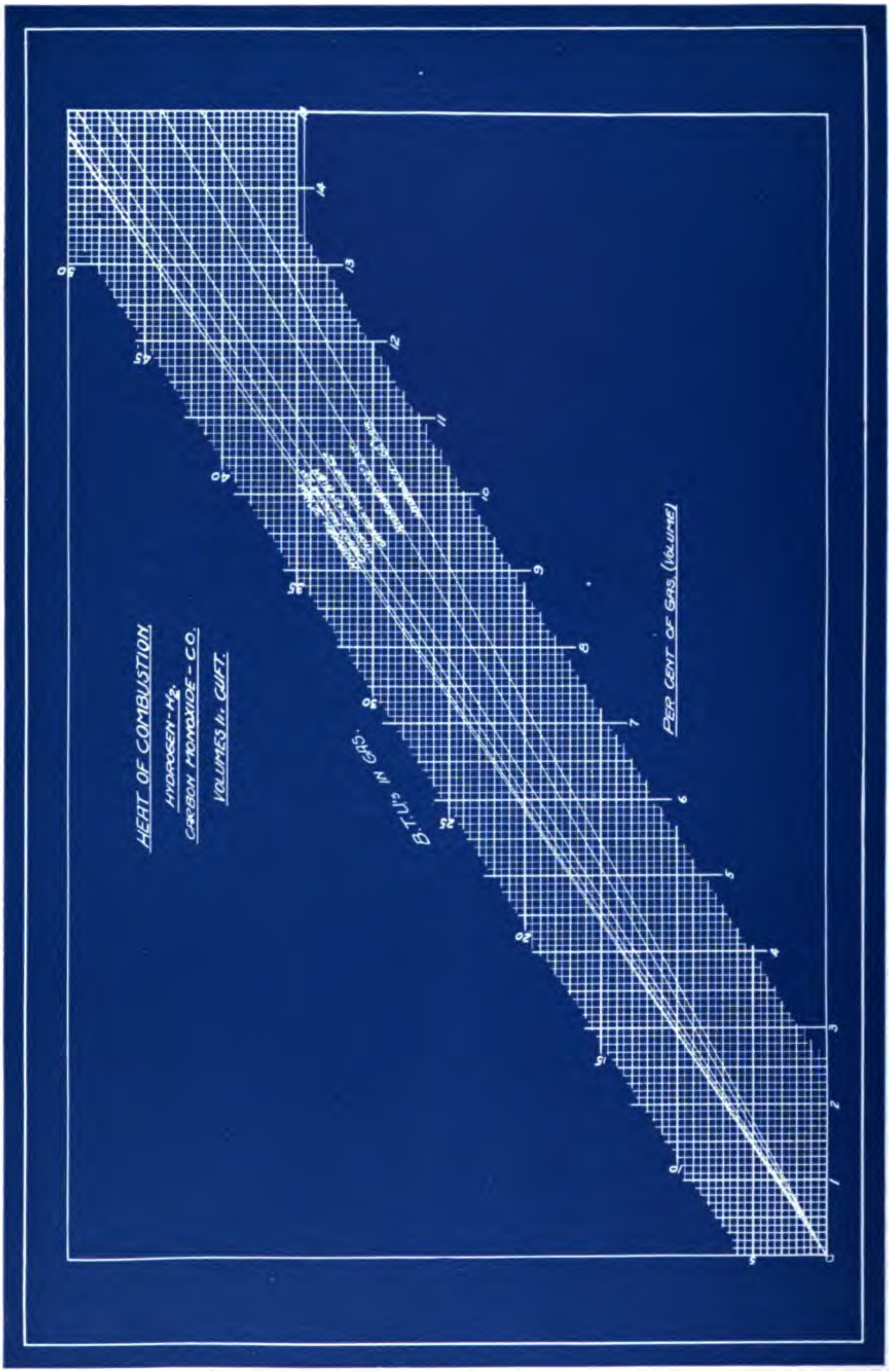


Figure 162—HEAT OF COMBUSTION (HYDROGEN AND CARBON MONOXIDE)

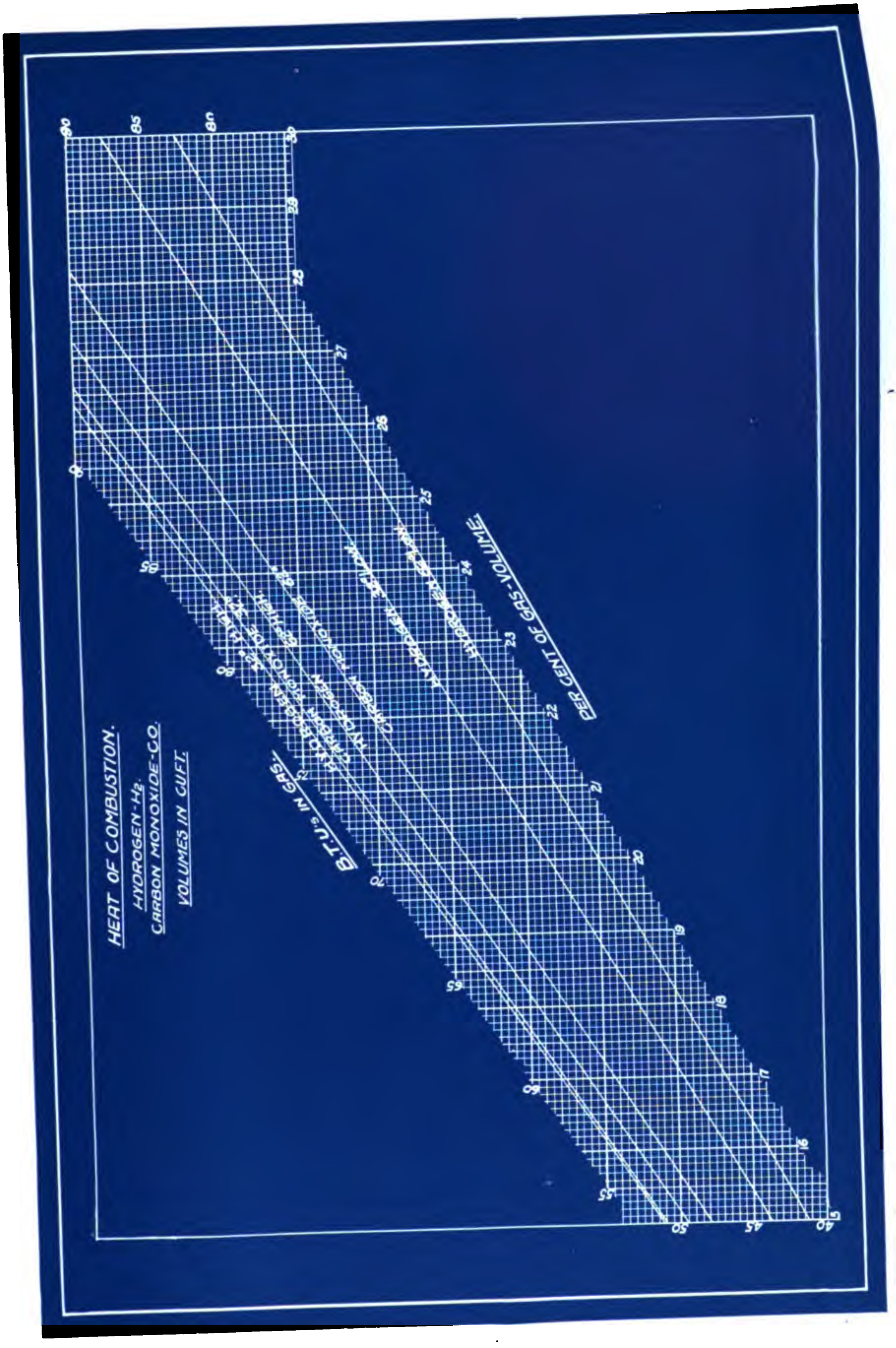


Figure 162 (Continued)—HEAT OF COMBUSTION (HYDROGEN AND CARBON MONOXIDE)

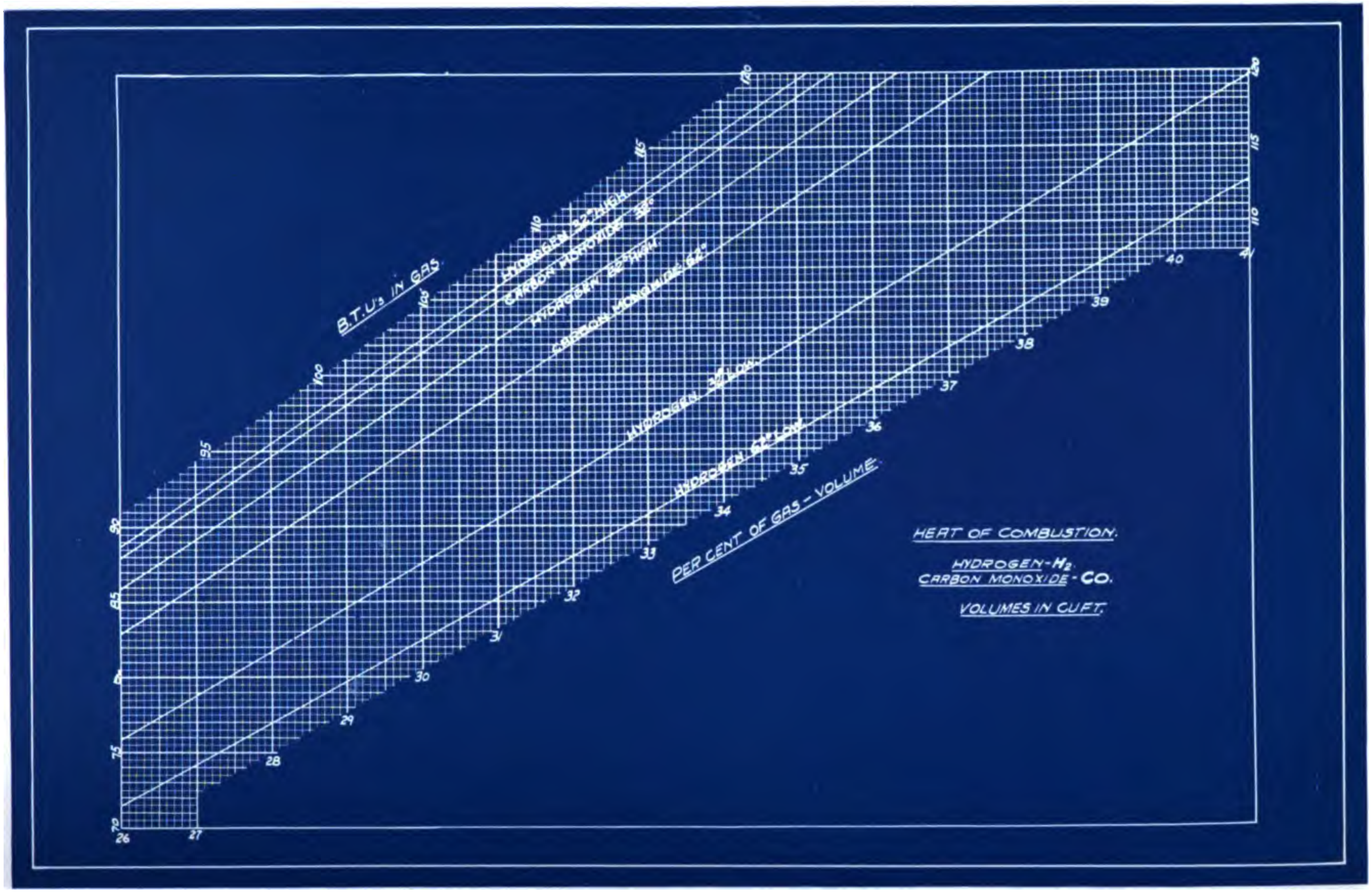


Figure 162 (Continued)—HEAT OF COMBUSTION (HYDROGEN AND CARBON MONOXIDE)

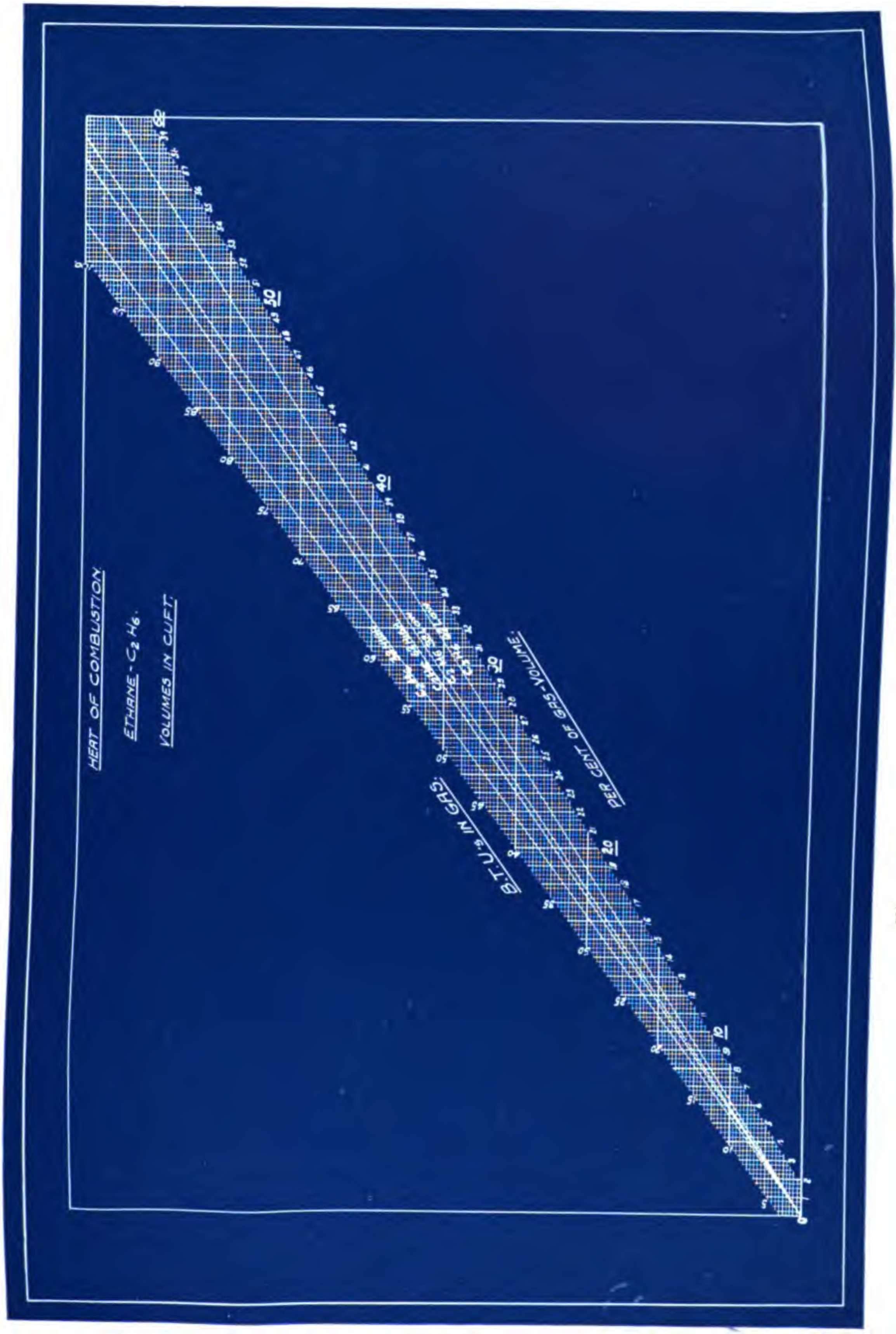


Figure 163—HEAT OF COMBUSTION (ETHANE)

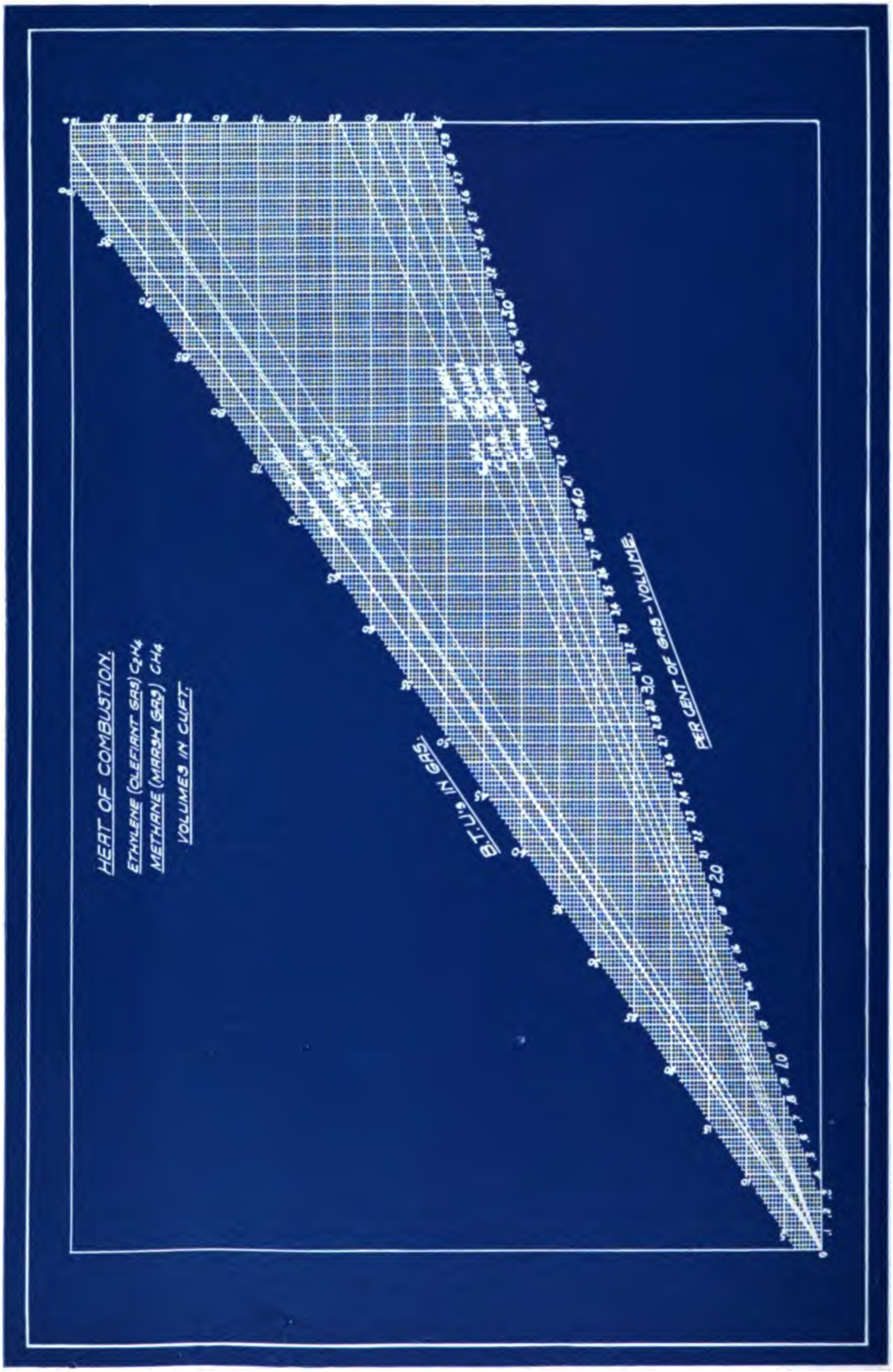


Figure 164—HEAT OF COMBUSTION (ETHYLENE AND METHANE)

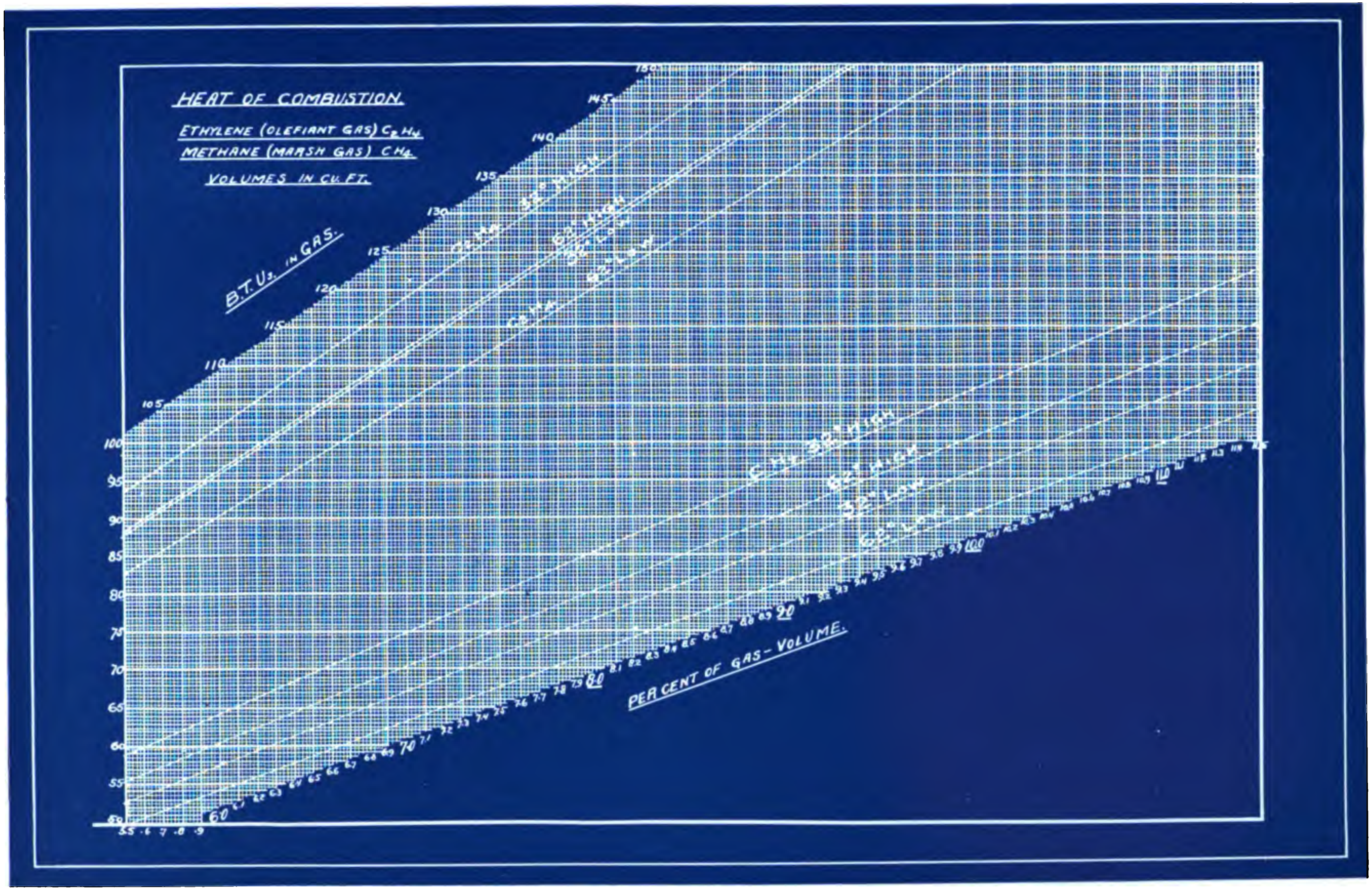


Figure 164 (Continued)—HEAT OF COMBUSTION (ETHYLENE AND METHANE)

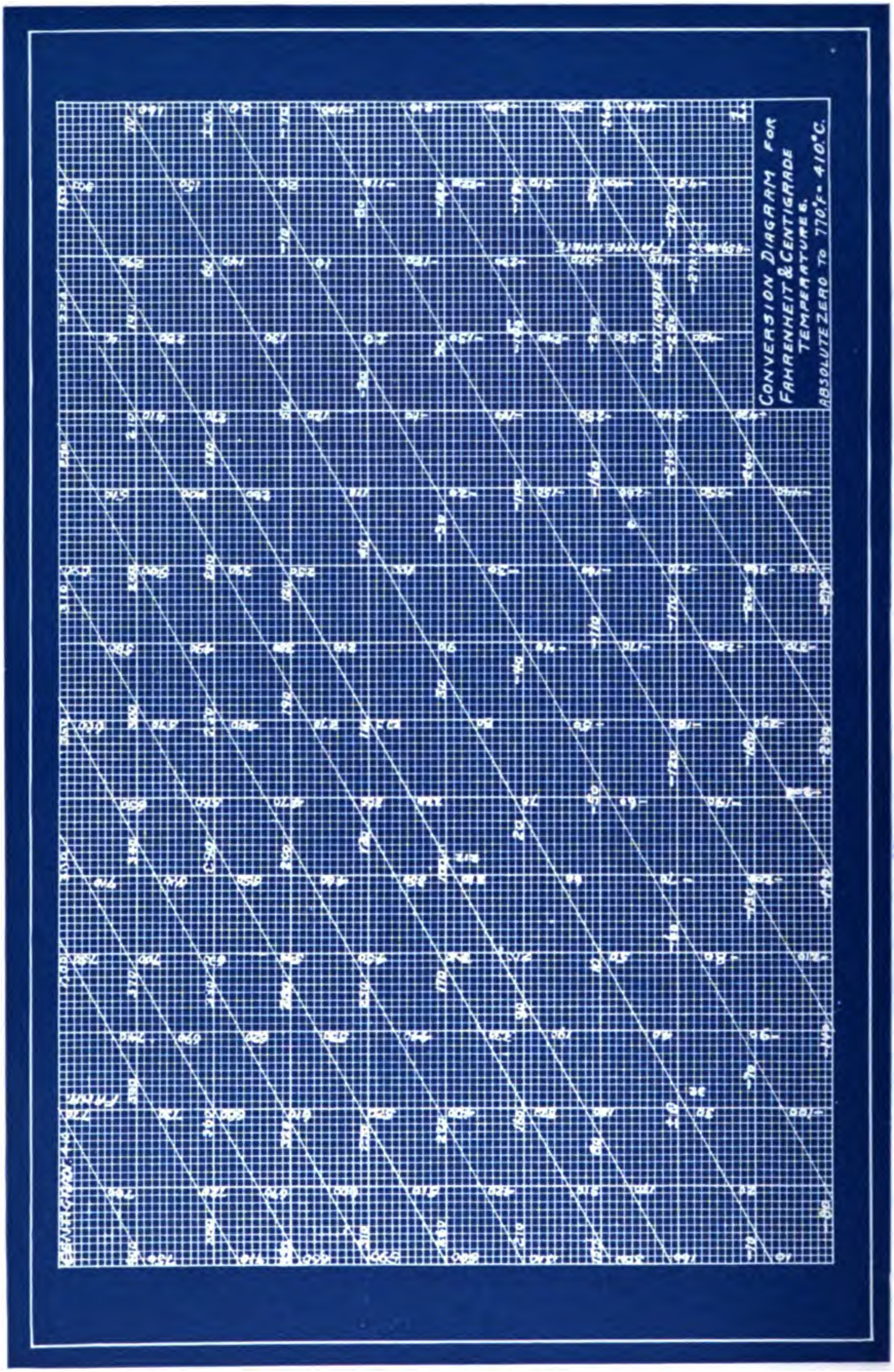


Figure 165—CONVERSION DIAGRAM OF CENTIGRADE AND FAHRENHEIT SCALES

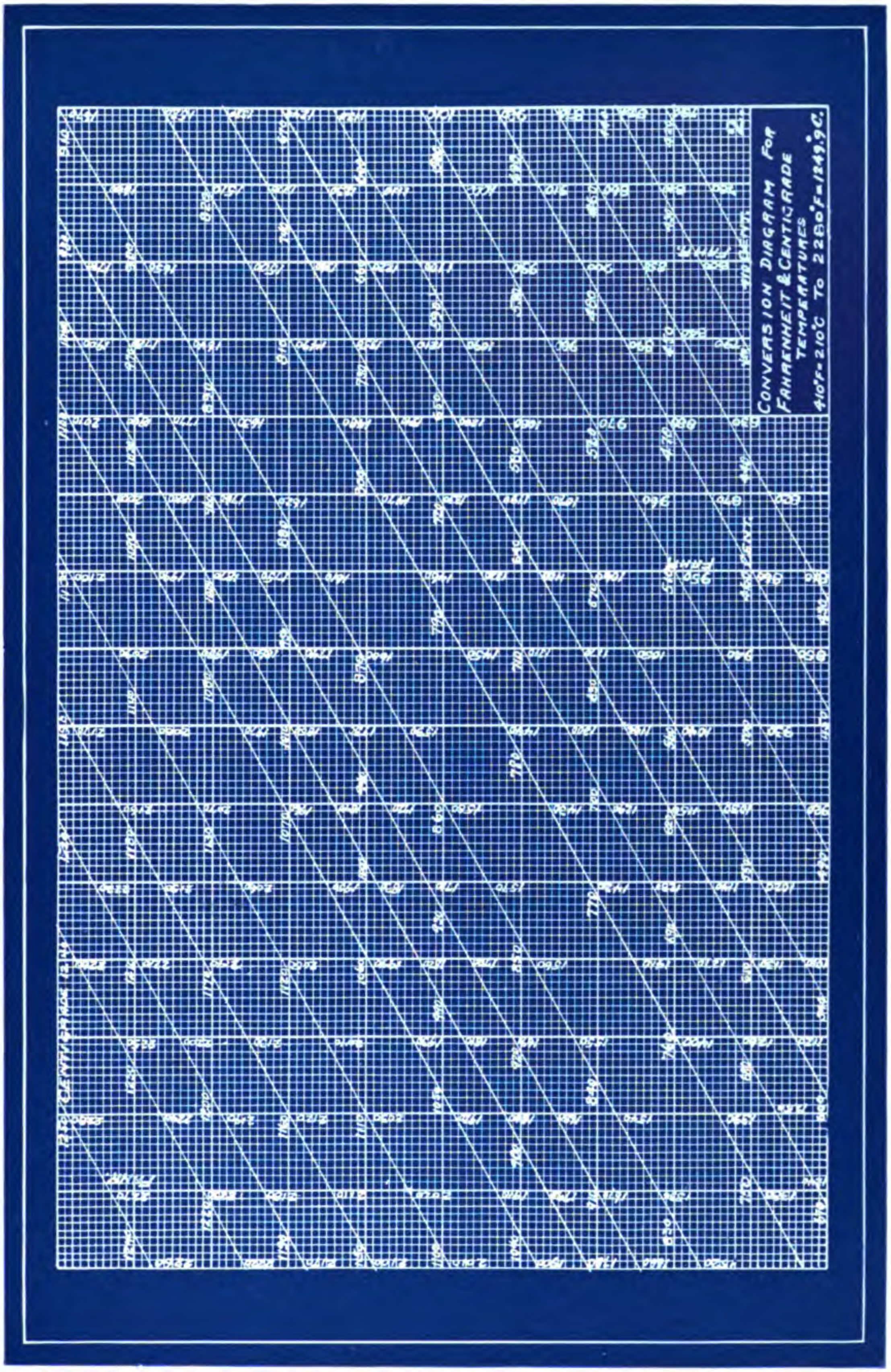


Figure 165 (Continued)—CONVERSION DIAGRAM OF CENTIGRADE AND FAHRENHEIT SCALES

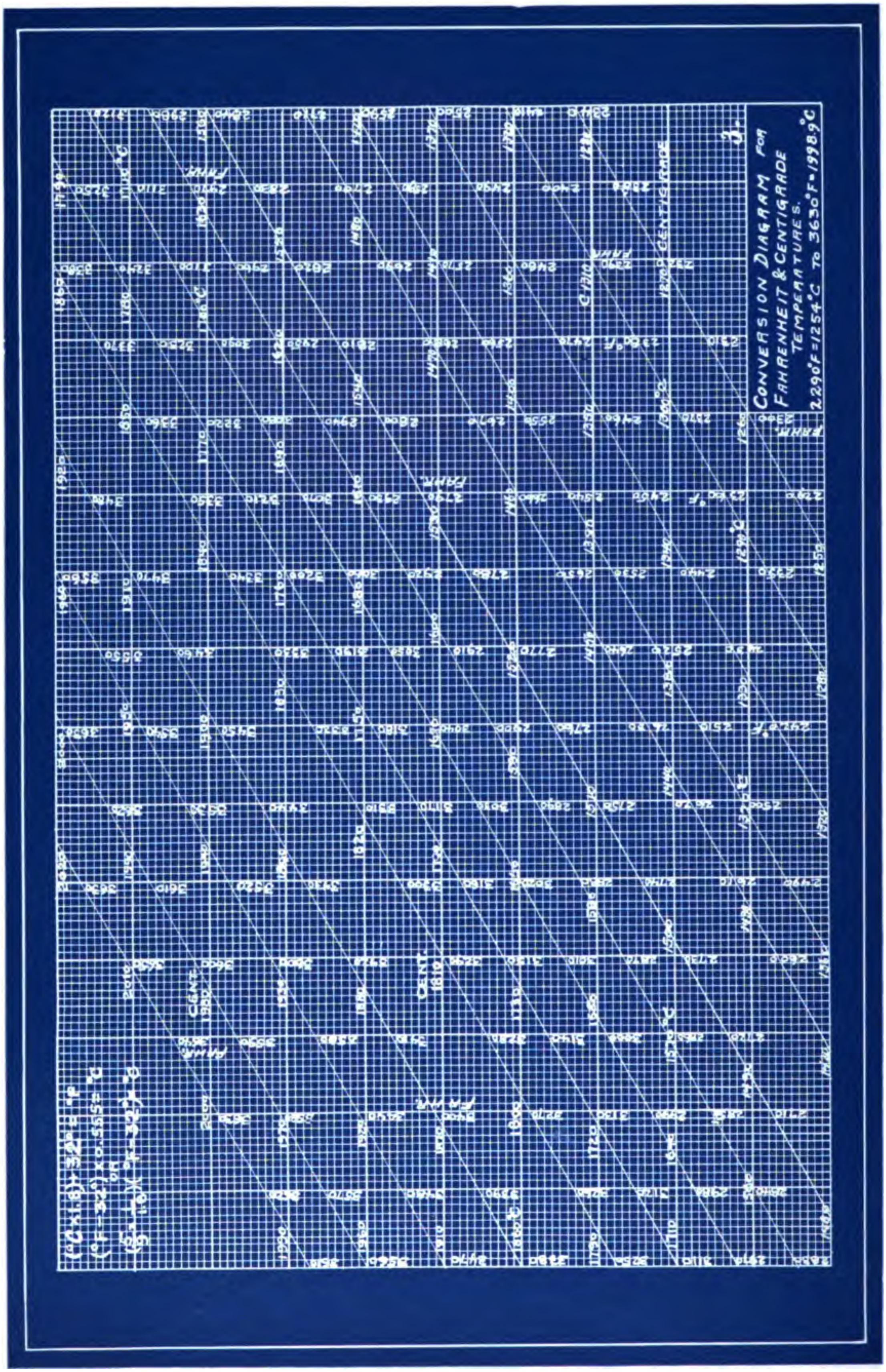


Figure 165 (Continued)—CONVERSION DIAGRAM OF CENTIGRADE AND FAHRENHEIT SCALES

Table No. 91

Steel Production in United States

Ingots and Castings—Gross Tons

Year	Open Hearth			Bessemer	Crucible	Electric	Misc.	Total
	Acid	Basic	Total					
1740					Developed by Huntsman—Sheffield, England			
1854				Developed by Bessemer—Sheffield, Eng.				
1855				Pat'd, England				
1856				Commercial Success in Sweden				
1861	Proposed by	Wm. Siemens						
1864	Developed in France by Martin							
1867	Process a Success—Birmingham, England							
1869				Introduced in United States				
1870	Commercially	Successful in	United States					
1880			100,850	1,074,260				
1898			2,230,292	6,609,017		Stassano F'ce Successful		
1908			7,836,729	6,116,755		55		14,023,247
1914	903,555	16,271,129	17,174,684	6,220,846	89,869	24,009	3622	23,513,030
1915	1,370,377	22,308,725	23,679,102	8,287,213	113,782	69,412	1527	32,151,036
1916	1,798,769	29,616,658	31,415,427	**11,059,039**	129,692	168,918	604	42,773,680
1917	2,061,386	32,087,507	34,148,893	10,479,960	126,716	304,543	495	45,060,607
1918	1,982,820	32,476,571	34,459,391	9,376,236	115,112	511,364	329	44,462,432
1919	1,229,382	25,719,312	26,948,694	7,271,562	63,572	384,452	2952	34,671,332

1918—212 Works Made Steel Ingots.
1918—280 Works Made Steel Castings.
1918—133 Works Made Alloy Steel.
1918— 10 Works Made Duplex Steel.
1918—400 Works Rolled Steel Finished Products.

1919—198 Works Made Steel Ingots.
1919—310 Works Made Steel Castings.
1919—141 Works Made Alloy Steel.
1919— 9 Works Made Duplex Steel.
1919—402 Works Rolled Steel Finished Products.

This Table Published through Courtesy of American Iron & Steel Institute.

Table No. 92

Typical Analyses of American Coals*

State	County	Kind of Sample	Coal Bed	As Received	Proximate dry coal		
				Moisture	Volatile Matter	Fixed Carbon	Ash
Alabama	Bibb	Mine	Youngblood	3.34	34.72	56.98	8.30
	Bibb	Mine	Thompson	3.10	36.00	57.7	6.3
	Jefferson	Mine	Pratt	2.38	26.53	68.47	5.00
	St. Clair	Mine	Harkness	3.39	31.77	59.08	9.15
Arkansas	Pope	Mine	Shinn Basin	2.07	10.02	80.48	9.50
	Logan	Mine	Paris	2.77	15.11	75.56	9.33
	Sebastian	Mine		3.21	15.33	75.07	9.60
Colorado	Boulder	Mine		20.45	38.38	55.30	6.32
	Garfield	Mine	"A"	5.32	38.33	52.39	9.28
	Huerfano	Mine	Robinson	6.90	37.53	53.38	9.09
	Las Animas	Mine		2.28	30.50	60.13	9.37
	Routt	Mine		12.20	40.78	53.96	5.26
	Routt	Mine	Crawford 11-ft	6.94	3.68	81.24	15.08
Illinois	Franklin	Mine	No. 7	11.50	30.17	59.51	10.32
	Saline	Mine	No. 5	5.56	35 44	54.33	9.23
	Williamson	Mine	No. 7	9.18	30.06	61.00	8.94
Indiana	Greene	Run-of-mine	No. 4	13.58	37.11	53.46	9.43
	Sullivan	Run-of-mine		12.03	40.53	47.10	12.37
	Vigo	Run-of-mine		13.53	40.25	47.31	12.44
Kentucky	Hopkins	Run-of-mine	No. 9	7.92	39.19	49.88	10.93
	Johnson	Mine	No. 1	6.43	38.69	57.85	3.46
	Webster	Mine	Owen (No. 11)	6.29	34.11	57.77	8.12
Maryland	Allegany	Mine	Upper Sewickley	3.4	15.5	77.8	6.7
	Allegany	Mine	Big Vein	2.7	14.5	78.0	7.5
Montana	Carbon	Mine	No. 5	9.31	37.64	50.54	11.78
	Dawson	Mine	Whole	34.55	54.00	35.00	11.00
	Fergus	Mine	McDonald Creek	14.13	31.87	56.40	11.73
	Yellowstone	Mine	Buckey	16.66	33.42	57.68	8.90
New Mexico	Colfax	Mine		2.12	36.84	51.31	11.85
	Rio Arriba	Mine	No. 1	1.71	36.89	56.07	7.04
	San Juan	Mine		15.79	41.55	47.32	11.13
Ohio	Belmont	Run-of-mine	No. 8	5.31	38.78	52.22	9.00
	Perry	Run-of-mine	No. 6	7.55	41.10	49.85	9.05
North Dakota	Stark	Mine		32.64	43.34	39.71	16.95
	Williams	Run-of-mine		38.92	41.81	49.37	8.82
Oklahoma	Coal	Mine	McAlester	7.07	39.18	49.16	11.66
	La Flore	Mine	McAlester	3.13	32.74	60.80	6.46
	Pittsburgh	Mine	McAlester	4.54	39.29	51.74	8.97
	Pittsburgh	Mine	Hartshorne	3.53	37.67	57.24	5.09
Pennsylvania	Allegheny	Mine	Pittsburgh	2.60	33.54	61.00	5.46
	Cambria	Mine	"B"	3.52	17.94	75.96	6.1
	Fayette	Mine	Pittsburgh	3.24	28.04	64.61	7.35
	Indiana	Mine	Upper Freeport or E	5.02	27.40	64.39	8.21
	Washington	Mine	Pittsburgh	1.44	35.12	58.61	6.27
	Westmoreland	Run-of-mine	Pittsburgh	3.98	29.30	60.12	10.58
	Schuylkill	Mine	Diamond	2.76	2.55	84.40	13.05
	Schuylkill	Mine	Mammoth Middle Split	2.80	1.19	90.75	8.06
	Sullivan	Mine	B-6 ft.	3.38	8.77	79.33	11.90
	Sullivan	Mine	B-Lower	3.4	9.7	78.2	12.09
Tennessee	Campbell	Mine	Rex	2.92	33.00	59.99	7.01
	Morgan	Run-of-mine	Brushy Mountain	5.59	35.61	54.05	10.34
Texas	Wood	Run-of-mine		33.85	41.57	47.39	11.04
Utah	Carbon	Mine	Upper	5.1	40.5	51.3	8.23
	Emery	Mine	Pugsley	4.0	42.6	51.2	6.17
	Summit	Mine	Wasatch	12.2	48.0	48.1	3.86
Virginia	Tazewell	Mine	Pocahontas No. 3	4.0	18.0	77.5	4.49
West Virginia	Fayette	Mine	Sewell	4.95	19.11	77.59	3.3
	Fayette	Mine	Fire Creek	3.6	17.46	76.16	6.38
	McDowell	Mine	Pocahontas No. 3	2.74	14.33	80.59	5.08
	Marion	Mine	Pittsburgh	3.13	34.02	58.24	7.74
	Raleigh	Mine	Beckley	4.7	13 5	81.9	4.6
Wyoming	Bighorn	Mine		17.67	33.13	57.65	9.22
	Carbon	Mine	No. 1	9.57	47.21	44.72	8.07
	Sheridan	Mine	Carney	22.76	44.30	51.25	4.45
	Sweetwater	Mine	Upper Van Dyke	15.91	39.52	56.04	4.44

*From Hofman—General Metallurgy.

Table No. 92 (Continued)

Typical Analyses of American Coals*

Ultimate dry coal					Air drying loss	Calorific value dry coal		Kind of coal
Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen		Calories	Btu.	
1.08	4.99	77.35	1.34	6.94	1.8	7,758	13,964	Bituminous
.44	5.13	78.70	1.28	8.18	1.4	7.775	14,000	Bituminous
1.50	5.02	83.67	1.57	3.24	1.5	8,244	14,839	Bituminous
2.42	4.97	76.40	1.58	5.48	1.8	7,685	13,832	Bituminous
1.78	3.46	81.97	1.50	1.79	1.4	7,773	13,991	Semi-anthracite
2.87	3.82	80.95	1.50	1.53	2.2	7,870	14,167	Semi-bituminous
3.22	3.50	80.97	1.57	1.14	2.4	7,799	14,038	Semi-bituminous
.43	4.81	70.61	1.41	16.42	14.1	6,651	11,972	Sub-bituminous
.80	4.93	71.57	1.67	11.75	3.0	7,290	13,122	Bituminous
.57	5.03	74.27	1.10	9.94	4.4	7,207	12,973	Bituminous
.51	5.09	75.97	1.11	7.95	1.5	7,834	14,101	Bituminous
.50	4.73	74.02	1.61	13.88	4.8	7,198	12,956	Sub-bituminous
.61	2.26	78.87	1.39	1.79	4.2	7,009	12,616	Anthracite
.68	4.52	73.89	1.22	9.37	6.4	7,163	12,893	Bituminous
3.04	4.81	72.80	1.38	8.74	3.6	7,437	13,386	Bituminous
.99	4.49	75.37	1.26	8.95	5.4	7,350	13,230	Bituminous
1.05	4.79	73.51	1.64	9.58	9.1	7,311	13,214	Bituminous
4.85	4.73	69.04	1.23	7.78	7.2	7,069	12,724	Bituminous
3.64	4.95	68.97	1.23	8.77	10.7	7,034	12,661	Bituminous
3.82	4.90	70.90	1.52	7.93	2.2	7,253	13,055	Bituminous
1.25	5.32	80.06	1.57	8.34	3.7	7,989	14,380	Bituminous
1.44	5.11	74.46	1.46	9.41	4.5	7,632	13,738	Bituminous
1.08	4.40	83.51	1.60	2.69	2.5	8,140	14,650	Semi-bituminous
1.02	4.40	82.92	1.87	2.33	1.7	8,070	14,520	Semi-bituminous
2.19	4.64	65.65	1.48	14.26	3.4	6,415	11,547	Sub-bituminous
1.68	4.22	64.78	.86	17.46	15.5	6,018	10,833	Lignite
4.30	4.06	69.72	.86	9.33	7.0	6,747	12,145	Bituminous
1.20	4.51	71.06	1.16	13.17	7.2	6,817	12,271	Sub-bituminous
.65	4.80	71.48	1.36	9.86	.5	7,359	13,246	Bituminous
.66	5.11	76.69	1.59	8.91	0.4	7,758	13,964	Bituminous
2.11	4.96	66.19	1.65	13.96	7.6	6,578	11,840	Sub-bituminous
3.52	5.07	74.68	1.18	6.55	3.9	7,535	13,563	Bituminous
3.07	5.02	72.50	1.40	8.96	4.5	7,288	13,118	Bituminous
5.26	3.74	58.69	.73	14.63	10.4	5,748	10,346	Lignite
.79	4.21	64.41	1.11	20.66	31.7	6,130	11,034	Lignite
3.92	4.68	69.28	1.55	8.91	3.0	6,856	12,341	Bituminous
.89	5.32	80.59	1.87	4.87	2.4	8,042	14,476	Bituminous
3.38	4.62	73.43	1.68	7.92	1.9	7,397	13,315	Bituminous
1.58	5.46	79.29	1.99	6.59	1.8	7,996	14,393	Bituminous
.79	5.24	80.25	1.49	6.77	1.4	8,034	14,461	Bituminous
1.10	4.55	85.06	1.27	1.92	2.8	8,222	14,800	Semi-bituminous
.98	4.99	80.61	1.27	4.80	1.8	7,992	14,386	Bituminous
2.04	4.92	80.26	1.48	3.09	4.2	7,931	14,276	Bituminous
.79	5.14	79.91	1.46	6.43	....	8,028	14,450	Bituminous
1.04	4.71	76.38	1.59	5.70	3.1	7,702	13,864	Bituminous
.56	1.97	81.47	.70	2.25	1.6	7,185	12,933	Anthracite
.92	1.63	86.78	.65	1.96	1.5	7,601	13,682	Anthracite
.65	3.31	81.18	1.04	1.92	2.6	7,535	13,617	Semi-anthracite
.84	3.37	80.59	.98	2.13	2.9	7,545	13,580	Semi-anthracite
1.17	5.02	77.21	1.67	7.92	1.5	7,734	13,921	Bituminous
3.42	4.89	74.23	1.72	5.40	4.3	7,558	13,604	Bituminous
.77	4.41	65.18	1.07	17.53	26.7	6,296	11,333	Lignite
.54	5.25	74.49	1.66	9.83	1.5	7,385	13,290	Bituminous
.41	5.29	76.01	1.30	10.82	.3	7,500	13,500	Bituminous
2.16	5.07	72.61	1.45	14.85	4.5	7,120	12,820	Sub-bituminous
.65	4.49	86.04	1.07	3.26	3.5	8,405	15,130	Semi-bituminous
.86	4.78	86.43	1.56	3.07	4.1	8,437	15,187	Semi-bituminous
.69	4.69	84.05	1.61	2.58	2.7	8,193	14,747	Semi-bituminous
.61	4.50	86.61	1.32	1.88	1.8	8,365	15,057	Semi-bituminous
.93	5.16	77.41	1.54	7.22	1.6	7,745	13,941	Bituminous
.87	4.40	86.36	1.56	2.21	4.1	8,360	15,050	Semi-bituminous
.20	4.11	69.33	1.02	16.12	6.3	6,537	11,767	Sub-bituminous
.43	4.91	69.47	1.45	15.67	1.4	6,910	12,438	Sub-bituminous
.45	4.53	71.06	1.32	18.19	6.6	6,783	12,209	Sub-bituminous
1.31	5.02	73.44	1.53	14.26	11.5	7,187	12,937	Bituminous

*From Hofman—General Metallurgy

Glossary

Acid Steel—Acid steel is steel made in a vessel or furnace having a silicious refractory lining such as ganister, silica brick or sand. The character of the lining profoundly affects the steel as the chemistry of the operation is determined by the character of the slag, and this is fixed by the chemical qualities of the lining.

Air Furnace—A reverberatory furnace on the hearth of which pig iron is melted by radiation of heat from the flame of a coal fire which is burned in a combustion chamber separated from the hearth by a bridge wall. The furnace is charged through a large side door or by lifting sections of the roof off for the purpose, making an opening capable of admitting large pieces of scrap too large for convenient melting in a cupola.

Alloy Metals—(a) **Alloy Cast Iron.** A cast iron having special and useful qualities due to the presence of another element than carbon.

(b) **Alloy Steel.** A steel having special and useful qualities due to the addition of a metal such as chromium, manganese, molybdenum, nickel, tungsten, uranium, vanadium, etc., in addition to the carbon which it contains.

Alundum—The commercial or trade name of fused bauxite prepared in an electric furnace. White alundum has less than 1% of impurities, while reddish alundum contains from 6% to 8%. The white alundum having a fusing point of 2050° C. to 2100° C. (3732° F. to 3812° F.) is used for furnace roofs, and can withstand a temperature which would melt a silica roof in 5 or 6 hours. The co-efficient of expansion is very low. Vapors from basic slag react unfavorably on it in the high temperatures of an electric furnace.

Anneal—To heat and slowly cool iron or steel to remove internal stresses which may exist due to original cooling conditions or to the result of working under the hammer or in the rolls. Hard steels are thus softened so they may be machined. The risk of cracking is reduced when steel is reheated for hardening or tempered. Annealing of castings of white iron of the proper kind changes a sufficient amount of the combined carbon into graphitic carbon, and renders the casting malleable.

Basic Iron—or Basic Pig is cast iron suitable for conversion into steel in a furnace having a basic lining. The sulphur should be less than 0.05. Silicon less than 1.07, whereas the phosphorus may run up to 3.5% or more, as it is eliminated through the basic flux of limestone which is possible due to the basic lining of the furnace.

Basic Steel—Steel made under basic conditions of furnace lining and operation.

Bath—The molten mass of metal in a converter or furnace undergoing conversion into steel.

Bed—The hearth or portion of an open hearth furnace which holds the metal during conversion into steel.

Bessemer Process—Bessemer Iron—Bessemer Steel—The process, raw material, and product, discovered, used and made in converting iron into steel through decarburizing pig iron by blowing air through the molten metal, is then recarburized, making steel. The process was invented by Sir Henry Bessemer in England in 1855, first made a commercial success in Sweden, reached its greatest development in the United States and now is superseded by the open hearth metal both as to quantity and quality of product, although the output of Bessemer steel is still very large.

Composition of Acid Bessemer Iron.

	United States		England	Sweden
	Acid	Basic	Acid	Acid
Silicon	0.8 to 1.5%	0.5 to 1.0%	1.95	0.97
Manganese	0.3 to 0.8%	0.2 to 3.0%	.086	3.06
Sulphur	less than 0.5.	0.5 to 1.0%	.048	trace
Phosphorus	less than 0.10	0.2 to 3.0%	.014	.019

Bessmer Iron (Basic Process) phosphorus over 0.10%.

Blister Steel—Steel made by heating in a closed box bars of wrought iron packed in powdered carbon, such as charcoal dust. The absorption of carbon by the metal is accompanied by formation on the surface of the bars of bubbles or blisters of ferrous oxide. When a sufficient amount of carbon has been taken up by the metal, the bars are then melted in crucibles and the product is then called crucible steel.

Bloom—The first form of wrought iron made by combining together a number of "balls" of iron from a puddling furnace into one mass in a "rotary squeezer." In steel manufacture a bloom is the rolled bar into which an ingot is shaped in the "blooming" or "cogging" mill. This bar is generally cut into shorter pieces or blooms for convenience in the subsequent operations of heating and rolling.

British Thermal Unit—Btu.—The amount of heat necessary to raise one pound of water at 62° F. through one degree Fahrenheit. 1 Btu. equals 0.555 cal.

Calorie—Cal.—The amount of heat necessary to raise one kilogram of water through one degree Centigrade. 1 cal. equals 1.8 Btu.

Carnot Cycle—The series of operations involved in the thermo-dynamic consideration of the conversion of heat into mechanical work.

Cast Iron—Metal produced by the blast furnace direct from iron ore which contains so high a percentage of carbon as to be unweldable. The line of division between it and steel is 2.2%. The carbon content runs up to 4%.

Cast Steel—Steel melted in crucibles from which it is cast usually into ingots. Other names for this steel are blister steel, crucible steel, shear steel, double shear steel, tool steel. The usual name is crucible steel, the others are obsolete.

Catalan Forge—Known also as the Corsican forge, a process still surviving in a few isolated places in Southern Europe by which iron was produced from the earliest ages down to the introduction of the blast furnace. Iron ore is reduced in a charcoal fire blown by an air blast produced by the suction of water falling down a partially filled pipe. The iron usually produced is deficient in carbon and somewhat hard and steely in character.

One hundred pounds of ore of 45 to 48% iron will produce about 31 lbs. of iron with a consumption of 340 lbs. charcoal, and the slag will carry 30% of iron.

Charcoal Hearth Cast Iron—Iron desiliconized and dephosphorized in a charcoal hearth but containing sufficient carbon to maintain its character as cast iron.

Charge—The material placed into a furnace for conversion into iron or steel.

Charging Machine—A machine invented by S. T. Wellman for charging open hearth and other iron working furnaces.

Converted Steel—A synonym of blister steel.

Crucible Steel—Steel finished by the crucible process irrespective of its carbon content or the process of manufacture prior to its finishing by melting in crucibles. For synonyms see "cast steel."

Checkers—Brick piled in a regenerator in such a way as to present a maximum of surface for absorbing heat from the waste gases of a furnace, and then yielding up the heat to incoming fresh air required for combustion of fuel in the furnace.

Chilled—Cast iron poured into moulds made up in part of metal, which by a rapid absorption of the heat of the fluid iron is rapidly cooled, making the surface of contact of a very hard white iron, in which the carbon is "combined" and does not appear as graphite.

Dead Burned Magnesite—Magnesian limestone calcined during which by driving off the carbon dioxide of the carbonate the basic oxide is left, which in the high temperature of the open hearth furnace lies quiescent or inert as compared with a heated carbonate, giving off the gaseous carbon dioxide.

Dead Melt—Molten steel which lies quiescent and free from the agitation or boiling due to the presence of ferrous oxide and occluded gases.

Duplex Process—A process of steel refining in which desiliconizing and partial decarburizing is carried on in one furnace and completed in another. Duplexing is possible with a combination of the Bessemer and open hearth processes, or a combination of open hearth and electric furnaces.

Ferro-Manganese—An iron alloy of iron and manganese of the following average composition, manganese 40% to 80%.

Carbon	6.20%	6.58%
Manganese	70.00%	82.00%
Silicon	1.14%	1.00%
Sulphur	trace	trace
Phosphorus	.09%	0.12%
Iron	22.30%	10.00%

In steel works the usual "ferro" is either one of 50% or 80% manganese.

Flaw—A physical defect in steel such as a crack, blow hole, blister, or pipe.

Fluid Slag—A slag which is sufficiently silicious to run easily at the working temperature of a furnace.

Fore Hearth—An expansion of the runner or pouring spout of a furnace to serve as a container into which the metal is tapped and from which it flows into the casting ladle.

Foundry—An iron works or establishment in which the metal is poured into moulds for the production of castings as a final product.

Foundry Iron—A pig iron for general foundry purposes of making castings. An approximate composition—

Silicon	1.0% to 4.0%
Manganese	0.0% to 1.5%
Sulphur	.01% to 0.05%
Phosphorus	0.20% to 1.5%
Carbon	Graphitic in excess of combined.

Gas Producer—An apparatus for the production of fuel gas by destructive distillation of a raw fuel such as coal and other carbonaceous substances.

Gas Valve—A valve admitting fuel gas to the regenerators of a furnace. The most practical and simple valve not only controls the gas flow to both regenerators but simultaneously handles the exhaust gases from the furnace to the stack. Less economical and satisfactory systems require several valves to do the same work.

Gray Forge Iron—Gray Pig Iron—Gray Cast Iron—A pig iron whose fractured surface is gray from the preponderance of graphitic carbon concealing to a large extent the faces of the iron crystals. Such iron runs from 0.5 to upwards of 2.0% of silicon, and 0.03 to 0.2 sulphur.

Heat—The mass of metal converted into steel at one operation, and hence one operation of conversion and consequently the time of a heat is (in continuous operation) the time from tap to tap.

Ingot—A mass of ductile metal cast with the intention of working it while hot by the hydraulic press steam hammer or rolling mill into a finished mercantile product.

Iron—Chemically the substance iron, having the chemical symbol Fe. Atomic weight 55.84. Specific Gravity 7.84. Metallurgically iron is either crystalline unweldable cast iron containing over 2.2% carbon or fibrous weldable wrought iron of less than 0.10 carbon.

Laboratory—That part of the open hearth furnace in which the thermo-chemical reactions between the fuel and the metal and slag of the bath occur.

Magnesite—A magnesian rock (found in the best composition in Syria and in Greece and in California), used for the basic lining of an open hearth furnace generally in the calcined condition.

Malleable Castings—Iron castings which are rendered malleable by subsequent treatment, without fusion.

Malleable Iron—Wrought Iron.

Malleable Pig Iron—Cast iron relatively free from graphite when cast and afterwards annealed whereby free carbon is obtained from the combined carbon.

Melter—The head man of a crew or shift engaged in the operation of an open hearth furnace. Immediately under him are the 1st, 2nd and 3rd melters, the door boys, crane men, etc., all of whom are engaged in working the furnace and making of repairs between heats.

Melting Furnace—Another name for an open hearth steel furnace.

Metalloid—In iron or steel metallurgy the metalloids or metal-like substances are silicon, carbon sulphur and phosphorus.

Metallurgy—The art of reducing metals from their ores and refining them to the point required to fit them for use in the metal industry.

Mottled or White Iron—Pig iron whose fracture shows whitish or spotted whitish on account of the absence of graphitic carbon as the major part of carbon is combined with the iron as a carbide Fe_3C.

The composition of mottled iron is as follows:

Silicon	0.1% to 1.0%
Manganese	0.1% to 1.0% and over
Sulphur	.05% to 0.30%
Phosphorus	.03% to 0.50%

Mould—A heavy cast iron container into which liquid steel is poured and cooled to form an ingot.

Open Hearth Furnace—A regenerative steel making furnace, the hearth of which is open or exposed to the flame of the gaseous burning fuel.

Open Hearth Steel—Steel made in open hearth furnace.

Pig Iron—Cast iron cast direct from the blast furnace made in bars of about 150 lbs. which are called pigs.

Ports—The passages through which the fuel gas enters and the waste gases leave a furnace.

Preheating Furnace—A furnace having an extension in which the charge is heated prior to its entrance into the hearth for melting.

Puddled Iron—Wrought iron made in a puddling furnace.

Recarbonization
Recarburization Adding carbon to refined metal in sufficient quantity to make a steel of a specified carbon content.

Recarburizers are anthracite, charcoal powder, coke breeze, ferro-manganese, liquid pig iron, spiegeleisen.

Recuperative Furnace—A furnace in which the incoming air for combustion is heated by waste heat of the furnace conducted through the walls but not by the aid of regenerators of the Siemens type.

Refined Cast Iron—A desiliconized cast iron.

Regenerator—The regenerator distinctly known as such and invented by Sir Wm. Siemens is a chamber filled with fire brick known as checkers, so piled as to permit a free flow of gases and air during which the hot waste furnace gases give up their heat to the checkers and then are diverted to another similar chamber, while the incoming air for the fuel combustion passing through the heated checkers is heated and thus carries back to the furnace heat which would be lost otherwise. With rapid reversals the only limit to the temperature attainable in a furnace is the melting temperature of the furnace refractories.

Refractories—A general term to include all materials used for furnace lining, etc., which are intended to form its bed walls, roof, etc. and withstand the high temperatures used. Such materials are the various kinds of fire-brick, fire-clay, bauxite, magnesite, chrome ore, dolomite, silica, and other highly infusible earthy substances.

Semi-Steel—An iron product of cupola melting in which 25% to 40% of steel scrap is melted with pig iron. The average analysis of this iron is—

Combined Carbon	0.8%	to 0.9%
Graphitic Carbon	2.4%	to 2.7%
Total	3.2%	to 3.6%
Silicon	1.2%	to 1.6%
Manganese	0.8%	to 2.0%
Sulphur	.04%	to 0.07%
Phosphorus	0.50%	to 0.70%

Tensile strength, 35,000 to 49,000 lbs. per sq. in.

Charge to cupola—

Pig iron	30% to 40%
Steel	20% to 33%
Remelt	50% to 27%

The analysis shows that this is not a steel at all, but a cast iron having a low percentage of combined carbon.

Reverberatory Furnace—An iron furnace in which the fuel—coal—is burned in a fire box separated from the hearth by a bridge wall, while the flame and heat of combustion sweeps over the metal on the hearth to a chinmey at the other end, and the bath is heated by heat radiated from the roof walls and gases of combustion.

Rust—The oxide of a metal, generally so called when adhering to the metal and specifically the oxide of iron.

Scrap—Metal in an unmerchantable form exept for use in remelting. Scrap has various names according to its origin such as for example—

Bloom Butts—excess or waste ends of bars.

Crop Ends —which are sheared off when cutting a rolled bar into blooms.

Ingot Butts —small fillings of ingot moulds which are too short to be used as ingots.

Punchings —waste metal obtained when punching rivet holes in steel plate and shapes.

Shapes—Fire brick having shapes and dimensions differing from the "9″ standard" brick.

Stool—A casting on which ingot moulds stand serving as a bottom to the mould.

Shear Steel—Double Shear Steel—A steel made by shearing the bars of blister steel made in the cementation process, which are then piled and welded by hammering or rolling. If this process is repeated the product is "double shear" steel.

Shut-Off Valve—A valve which completely closes the pipe or flue in which it is used, as compared with other forms which are not designed to be actually tight against leakage.

Siemens Valve—A gas or air reversing valve used for admission of cold air or fresh gas to the regenerators and the passage to the stack of waste gases alternately from one or the other of the furnace regenerators. The entering air or gas is controlled by a mushroom valve and the waste gases by an oscillating butterfly valve all in the one framework. This is now rendered obsolete by the invention of the W-S-M gas reversing valve.

Silico Spiegel—An iron used for making steel of a desired silicon content, composed of 8% to 15% silicon, 15% to 20% manganese and 1.0% to 1.5% carbon.

Skewback—Brick from which the roof arch spring.

Slag—The solid waste by-product of a thermo-metallurgical operation. It is composed of silicates of calcium, magnesium, iron, manganese and other metals and in some instances of phosphates and sulphides of some of the above named substances.

Slag Pocket—A chamber through which the waste gases pass before entering the regenerators, the purpose being to receive particles of slag carried over from the furnace, and prevents their clogging up the regenerators.

Spiegeleisen—A cast iron containing from 7% to 40% of manganese, generally 20% and issued as a recarburizer.

Standard 9″ Brick—A fire-brick of rectangular sides all of whose angles are 90° and whose dimensions are 9″x4½″x2¼″ containing 100 cu. in. In figuring fire-brick where "shapes" and "standard 9″ straights" are figured from the volume of masonry, it is assumed that the average brick contains 95 cu. in. An additional allowance of 5% is made to cover breakage, as none but whole brick are allowable in fire-brick masonry.

Steel—A ferruginous alloy of iron and carbon with various other metals which is malleable at least in some range of temperature and is cast into an initially malleable mass and is capable of hardening by sudden cooling or quenching. Ordinary steel is supposed to contain enough carbon over 0.3% to harden usefully when quenched from its critical temperature. Custom has included metal which will not harden and may run as low as 0.06%, which metal is called soft or mild steel.

Steel Casting—Steel cast in a special form moulded from a pattern and intended for use without hammering or rolling to shapes.

Steel Works or Steel Mill—As distinguished from a foundry, an installation of furnaces and other steel making and handling appliances whose output is steel ingots (as distinguished from castings) and which are prepared for ultimate use by pressing, hammering or rolling.

Tapping Hole—The outlet of a furnace through which the metal and slag is discharged.

Triplex Process—A process of making steel in which the Bessemer converter, open hearth and electric furnaces are used in the order named.

Uptake—In an open hearth furnace, the passage from the regenerators to the furnace, through which the gases pass.

Washed Metal—Cast iron of which most of the silicon and phosphorus has been eliminated by the Bell-Krupp process and in which the carbon content remains high enough to keep it a cast iron.

White Cast Iron—Iron of a silvery or white fracture due to absence of sufficient graphitic carbon to color it.

Wrought Iron—Slag bearing malleable iron, incapable of hardening when quenched. The carbon content is less than 0.06%.

THE
WELLMAN-SEAVER-MORGAN COMPANY

GENERAL OFFICE Cleveland, Ohio

WORKS

Open Hearth Foundry	Cleveland, Ohio
Shops	Cleveland, Ohio
Shops	Akron, Ohio

DISTRICT OFFICES

New York, N. Y. Philadelphia, Pa. Atlanta, Ga.
San Francisco, Calif. Mexico City, Mexico

ALLIED COMPANIES

Wellman Smith Owen Eng. Corp. Ltd.,	London, Eng.
Schneider Et Cie	Paris, France
Canadian Ingersoll Rand Co.	Montreal, Canada

THE WELLMAN-SEAVER-MORGAN COMPANY

Engineers and Manufacturers of Equipment for Handling, Transporting and Manufacturing Raw Materials into Finished Products

PARTIAL LIST OF OUTPUT

Steel Works

Complete Steel Works
Wellman Mechanical Gas Producers
Hot Metal Mixers
Wellman Open Hearth Furnaces, Stationary and Tilting type
Continuous Heating Furnaces with Pushers
Gantry Cranes
Water Cooled Ports, Doors, Jambs
Special Heavy Duty Cranes
W-S-M Gas Reversing Valves
Chimney Shut-off Valves
Charging Machines of high, low and crane type
Manipulators for ingots, blooms, slabs, wheels, etc.
Hydraulic or Electric Tilting and Operating Devices
Cast Steel Charging Boxes and Cars

Coal and Ore Handling Machinery

Traveling Bridges with Grab Buckets
Coal or Ore Unloaders
Car Dumpers
Transfer Cars
Boat Loaders
Bucket Handling Cranes
Revolving Derricks
Excavating Buckets
Car Haulages
Weighing Lorries

Coke Oven Machinery

Coke Pushers
Coke Levelers
Door Extractors
Larry Charging Cars
Coke Quenchers
Coke Loaders

Heavy Cranes for

Marine Work with Pontoons
Concrete Handling
Shipbuilding
Cargo Handling
Steel Plants
Heavy or Particular Service calling for special designs

Land and Marine Terminals

Appliances for rapid and economical handling of general cargoes and freight at railroad and steamship terminals, or in Navy Yards, and for fueling ships

Hoisting and Mining Machinery

Steam or Electric Hoisting Plants
Mine Cages
Skips for Coal, Ore, or Water
Revolving Car Tipples

Hydraulic Power Developments

Hydraulic Power Plants
Turbines, horizontal or vertical, with spiral or steel plate, cylindrical casings, or for open flumes
Turbines equipped with cast steel, cast iron or bronze runners
Wellman Hydraulic Valves

Rubber Machinery

Rubber Calenders
Mixing and Grinding Mills
Tubing Machines
Tire Applying Presses
Rimming Presses
Accumulators
Fabric Dryers
Vulcanizing Presses
Molds and Cores
Iron and Steel Castings
Jobbing Work

CHAPTER XXVI

Wellman-Seaver-Morgan Company Installations

The following partial list of customers shows the extent to which we have assisted the manufacturers of steel, in their efforts to increase the amount and improve the quality of their product:

Wellman Open Hearth Steel Furnaces Built

		No.	Size	Type	Fuel
J. A. & P. E. Dutcher	Milwaukee, Wis.	1	3-T	Tilting	Pro. Gas
Lorain Steel Company	Johnstown, Pa.	1	5-T	Tilting	Oil
The Crane Company	Chicago, Ill.	1	5-T	Tilting	Oil
Firth Stirling Co.	McKeesport, Pa.	1	5-T	Tilting	Oil
Nicopol Mariopol Mining & Metallurgical Co.	Moscow, Russia	1	5-T	Tilting	Oil
Prescott Co.	Muskegon, Mich.	1	5-T	Tilting	Oil
Crucible Steel Co.	Pittsburgh, Pa.	1	6-T	Tilting	Oil
Industrial Mexicana	Chihuqhua, Mex.	1	10-T	Tilting	Oil
Buckeye Malleable Iron	Columbus, O.	1	10-T	Tilting	Pro. Gas
McCormick Company	Chicago, Ill.	2	12-T	Tilting	Pro. Gas
Standard Steel Works	Burnham, Pa.	1	15-T	Tilting	Pro. Gas
Atlas Crucible Steel Co.	Dunkirk, N. Y.	1	15-T	Tilting	Oil
Hamilton Iron & Steel Co.	Hamilton, Ont.	2	15-T	Tilting	Pro. Gas
Falk Company	Milwaukee, Wis.	2	15-T	Tilting	Pro. Gas
Shickle-Howard-Harrison	St. Louis, Mo.	4	15-T	Tilting	Pro. Gas
Washburn Wire Co.	Phillipsdale, R. I.	2	15-T	Tilting	Pro. Gas
S. T. Wellman	Chester, Pa.	1	15-T	Stationary	Oil
U. S. A. War Dept.	Watertown Arsenal, Mass.	1	15-T	Tilting	Oil
Cambria Steel Co.	Johnstown, Pa.	2	20-T	Tilting	Oil
Vulcan Iron Works	Wilkes-Barre, Pa.	1	20-T	Stationary	Oil
Page Woven Wire Fence Co.	Monessen, Pa.	2	20-T	Tilting	Pro. Gas
British Westinghouse Co.	Sheffield, Eng.	2	20-T	Tilting	Pro. Gas
Vickers Company	Sheffield, Eng.	1	20-T	Tilting	Pro. Gas
British Westinghouse Co.	Sheffield, Eng.	2	20-T	Tilting	Pro. Gas
Buckeye Malleable Iron Co.	Columbus, Ohio	1	20-T	Tilting	Pro. Gas
Shickle-Harrison-Howard Co.	St. Louis, Mo.	1	20-T	Tilting	Oil
Sargent Company	Chicago, Ill.	1	20-T	Tilting	Oil
Wellman-Seaver-Morgan Co.	Cleveland, O.	1	20-T	Tilting	Oil
Wellman-Seaver-Morgan Co.	Cleveland, O.	1	20-T	Stationary	Oil
Gould Coupler Co.	Depew, N. Y.	2	20-T	Stationary	Oil
Halcomb Steel Co.	Syracuse, N. Y.	1	20-T	Tilting	Oil
Marion Steam Shovel Co.	Marion, Ohio	1	20-T	Stationary	Oil

		No.	Size	Type	Fuel
Illinois Steel Co.	Chicago, Ill.	2	25-T	Tilting	Pro. Gas
Vickers Company, Ltd.	Sheffield, Eng.	1	30-T	Tilting	Pro. Gas
Brymbo	Eng.	2	30-T	Tilting	Pro. Gas
Round Oak	Eng.	2	30-T	Tilting	Pro. Gas
Brown-Bailey	Eng.	1	30-T	Tilting	Pro. Gas
Trubia Arsenal	Trubia, Spain	1	30-T	Tilting	Pro. Gas
Wickwire Bros. Co.	Cortland, N. Y.	3	30-T	Tilting	Pro. Gas
Algoma Steel Co.	Sault Ste. Marie, Canada	2	30-T	Tilting	Pro. Gas
Atlanta Steel Hoop Co.	Atlanta, Ga.	2	35-T	Stationary	Pro. Gas
U. S. A. War Dept.	Watertown Arsenal, Mass.	2	35-T	Stationary	Oil
Nova Scotia Steel & Coal Co.	New Glasgow, N. S.	1	40-T	Stationary	Pro. Gas
Grand Crossing Track Co.	Chicago, Ill.	2	40-T	Stationary	Pro. Gas
Nova Scotia Steel Co.	New Glasgow, N. S.	3	40-T	Stationary	Pro. Gas
Tennessee Coal Iron & R. R.	Ensley, Ala.	10	50-T	Tilting	Pro. Gas
Guest Keen & Co., Ltd.	Cardiff, Wales	4	50-T	Tilting	Pro. Gas
American Steel & Wire Co.	Worcester, Mass.	8	50-T	Tilting	Pro. Gas
Nova Scotia Steel Co.	New Glasgow, N. S.	1	50-T	Tilting	Pro. Gas
Illinois Steel Co.	Chicago, Ill.	4	50-T	Tilting	Pro. Gas
Vickers Co., Ltd.	Sheffield, England	1	50-T	Tilting	Pro. Gas
N. E. Steel Company, Ltd.	Middlesborough, Eng.	2	50-T	Tilting	Pro. Gas
Standard Steel Works	Burnham, Pa.	1	50-T	Tilting	Pro. Gas
Tennessee Coal Iron & R. R.	Ensley, Tenn.	2	50-T	Stationary	Pro. Gas
Imperial Japanese Gov't.	Kure Arsenal, Japan	2	50-T	Tilting	Pro. Gas
Frodingham Iron & Steel Co.	Doncaster, England	1	100-T	Tilting	Pro. Gas
Soc. Metallurgica Duro Felguera	La Felguera, Spain	1	100-T	Tilting	Pro. Gas
Guest Keen & Co., Ltd.	Cardiff, Wales	1	160-T	Tilting	Pro. Gas
Pencoyd Iron Works	Pencoyd, Pa.	1	170-T	Tilting	Pro. Gas
Imperial Steel Works	Kobe, Japan	2	200-T	Tilting	Pro. Gas

Wellman-Seaver-Morgan Company Hot Metal Mixers Built

		No.	Size	Type	Fuel
Hamilton Iron & Steel Co.	Hamilton, Ont.	1	150-T	Tilting	Nat'l Gas
Tennessee Coal Iron & R. R.	Ensley, Ala.	1	200-T	Tilting	Pro. Gas
Union Steel Co.	Donora, Pa.	1	200-T	Tilting	Nat'l Gas
Imperial Steel Works	Kobe, Japan	1	250-T	Tilting	Nat'l Gas
Glengarnock Iron & Steel Co.	Scotland	1	250-T	Tilting	Nat'l Gas
Lackawanna Steel Co.	Buffalo, N. Y.	1	300-T	Tilting	Nat'l Gas

Wellman-Seaver-Morgan Company Annealing Furnaces Built

		No.	Size of Bed	Fuel
Buckeye Malleable Iron Co.	Columbus, O.	1	10'-0"x10'-0"	Coal
McCormick Company	Chicago, Ill.	14	10'-0"x35'-0"	Nat. Gas Powd. Coal
Wellman-Seaver-Morgan Co.	Cleveland, O.	1	10'-0"x20'-0"	Coal & Gas
Gould Coupler Co.	Depew, N. Y.	1	10'-0"x20'-0"	Coal

Wellman-Seaver-Morgan Company Heating Furnaces

			No.	Size of Bed	Fuel
Wickwire Bros.	Cortland, N. Y.	Cont.	1	7′-0″x36′-0″	Oil
Wickwire Bros.	Cortland, N. Y.	Cont.	1	7′-0″x36′-0″	Coal
Standard Steel Works	Burnham, Pa.	Cont.	1	7′-0″x26′-0″	Coal
Standard Steel Works	Burnham, Pa.	Cont.	1	4′-5″x30′-0″	Coal
Elyria Iron & Steel	Elyria, O.	Cont.	1	12′-0″x21′-0″	Coal
Atlanta Steel Hoop Co.	Atlanta, Ga.	Ingot	2	7′-0″x37′-3″	Coal
Forged Steel Wheel Co.	Butler, Pa.	Slab	1	8′-0″x35′-0″	Pro. Gas
Forged Steel Wheel Co.	Butler, Pa.	Reheating	1	8′-0″x28′-0″	Pro. Gas
Detroit Copper Co.	Detroit, Mich	Billet	1	6′-0″x16′-0″	Coal
Dominion Iron & Steel	Sidney, N. S.	Ingot	1	15′-0″x36′-0″	Pro. Gas
Standard Steel Car Co.		Plate	1	7′-6″x 6′-0″	Oil
Standard Steel Car Co.		Plate	1	7′-6″x12′-0″	Oil
Buffalo Foundry Co.	Buffalo, N. Y.	20-T Air Force	1	6′-0″x16′-0″	

Wellman-Seaver-Morgan Company Core Ovens

			No.	Size of Bed
Tenn. Coal Iron & R. R.	Ensley, Ala.	Drying	1	7′-9″x24′-0″x9′-0″
Westinghouse Mach. Co.		Drying	1	22′-0″x22′-0″x9′-0″
Buckeye Malleable Co.	Columbus, O.	Mould	1	12′-0″x35′-0″x8′-0″
Buckeye Malleable Co.	Columbus, O.	Couplers	1	8′-2″x12′-0″x8′-0″
Buffalo Foundry Co.	Buffalo, N. Y.		1	12′-0″x25′-0″x12′-0″
Buffalo Foundry Co.	Buffalo, N. Y.		1	20′-0″x25′-0″x16′-9″
Buffalo Foundry Co.	Buffalo, N. Y.		1	17′-0″x25′-0″x14′-0″
Buffalo Foundry Co.	Buffalo, N. Y.		1	25′-0″x25′-0″x15′-9″
Buffalo Foundry Co.	Buffalo, N. Y.		1	24′-0″x11′-1½″x8′-0″
Wellman-Seaver-Morgan	Cleveland, O.	Cores	1	9′-0″x12′-0″x8′-0″
Wellman-Seaver-Morgan	Cleveland, O.		1	16′-0″x30′-6″x10′-0″
Wellman-Seaver-Morgan	Akron, O.	General	1	17′-5″x32′-0″x12′-0″
British Westinghouse Co.	Sheffield, Eng.	Drying	1	11′-10″x18′-6″x7′-6″
Otis Steel Company	Cleveland, O.	Drying	1	13′-10¾″x17′-½″x12′-0″
Otis Steel Company	Cleveland, O.	Core	1	10′-0″x13′-0″x10′-0″
Otis Steel Company	Cleveland, O.	Core	1	5′-0″x10′-0″x8′-0″
Otis Steel Company	Cleveland, O.	Revolving	1	6′-3″x6′-3″x6′-0″
Marion Steam Shovel Co.	Marion, O.	Core	1	9′-0″x13′-0″x8′-0″
Marion Steam Shovel Co.	Marion, O.	General	1	17′-0″x28′-0″x12′-0″

Wellman Mechanical Gas Producers

Partial List of Users

Over 1000 in Use

Name	No. Producers
American Rolling Mill Company	30
American Sheet & Tin Plate Company	32
American Steel & Wire Company	56
Bethlehem Steel Company	54
Byers, A. M.	6
Cambria Steel Company	10
Carbon Steel Company	10
Carnegie Steel Company	121
Colorado Fuel & Iron Company	6
Corrigan, McKinney & Company	30
Follansbee Glass Company	8
Ford Motor Company	6
Forged Steel Wheel Company	26
Granby Mining & Smelting Company	12
Hikoshima Zinc Refining Company	2
Highland Glass Company	3
Imperial Steel Works	2
Indiana Steel Company	38
Indianapolis Gas Company	4
Inland Steel Company	36
Jones & Laughlin Steel Company	40
Lackawanna Steel Company	39
Mark Manufacturing Company	22
Maryland Steel Company	9
Michigan Alkali Company	7
Midvale Steel Company	17
Mineral Point Zinc Company	15
Minnesota Steel Company	36
Mississippi Glass Company	2
N. & G. Taylor Company	4
National Carbon Company	4
National Tube Company	42
New Jersey Zinc Company	42
Otis Steel Company	10
Pencoyd Iron Company	15
Penn Seaboard Steel Company	3
Philadelphia Quartz Company	1
Pittsburgh Crucible Steel Company	29
Pittsburgh Steel Company	36
Railway Steel Spring Company	8
Republic Iron & Steel Company	32
Semet-Solvay Company	6
Standard Steel Works	16
Tennessee Coal, Iron & Railroad Company	16
Trumbull Steel Company	26
United Alloy Steel Company	1
Upson Nut Company	15
Youngstown Sheet & Tube Company	18
Wellman-Seaver-Morgan Co.	1

Wellman-Seaver-Morgan Company Charging Machines

Algoma Steel Corporation, Ltd.	Sault Ste. Marie, Ontario
Soc. Anonyme des Forges et Fonderies de Montataire	France
Acieres d'Anvers	Belgium
Baldwins, Ltd.	England
Beardmore, Ltd.	England
British Westinghouse Elect. & Mfg. Company	Trafford Park, England
Bengal Iron & Steel Company	India
The Bucyrus Company	S. Milwaukee, Wis.
Carnegie Steel Company Plants	5 Plants
Cia. Industrial Mexicano	Mexico
Cargo Fleet Iron Company, Ltd.	England
Colville & Sons, Ltd.	England
Drain Steel Company	Holmes, Del. Co., Pa.
Dominion Iron & Steel Company	Sydney, N. S.
Frodingham Iron & Steel Company	England
Guest, Keen & Nettlefolds, Ltd.	England
Hickman & Company, Ltd.	England
Illinois Steel Company	So. Chicago, Ill.
Indiana Steel Company	Gary, Ind.
Imperial Steel Works	Japan
Kladno Steel Works	Moravia
Kure Naval Arsenal	Japan
Llanelly Steel Company, Ltd.	England
LaBelle Iron Works	Steubenville, Ohio
Lukens Iron & Steel Company	Coatsville, Pa.
Soc. Metallurgica Duro Felgueir	Spain
Marion Steam Shovel Company	Marion, Ohio
Mesta Machine Company	Pittsburgh, Pa.
Midvale Steel & Ordnance Company	Philadelphia, Pa.
McConway Torley Company	Pittsburgh, Pa.
Nova Scotia Steel & Coal Company, Ltd.	New Glasgow, Canada
Nicopol Mariopol Mining & Metallurgical Company	Russia
U. S. Navy Ordnance Plant	S. Charleston, W. Va.
National Enamelling & Stamping Company	Granite City, Ill.
National Tube Company	Lorain, Ohio
National Tube Company	McKeesport, Pa.
Noble Electric Steel Company	San Francisco, Cal.
Oesterreische Alpine Montaigne Gesellschaft	Austria
Otis Steel Company	Cleveland, Ohio
Park Gate Iron & Steel Company, Ltd.	England
Pacific Coast Steel Company	San Francisco, Cal.
Pacific Coast Steel Company	Portland, Oregon
Pacific Coast Steel Company	Seattle, Wash.
Page Steel & Wire Company	Adrian, Mich.
Pardee Works, The A.	Perth Amboy, N. J.
Phoenix Iron Company	Phoenixville, Pa.
Pressed Steel Car Company	McKees Rocks, Pa.
Portsmouth Steel Company	Portsmouth, Ohio
Round Oak Works	England
Railway Steel Spring Company	Latrobe, Pa.
Republic Iron & Steel Company	Youngstown, Ohio.

Riter-Conley Manufacturing Company	Pittsburgh, Pa.
Roeblings Sons Company, J. A.	Trenton, N. J.
Rombarher Iron & Steel Company	Germany
Steel Company of Canada, Ltd.	Hamilton, Canada
Summers & Sons, Ltd., J.	England
Sharon Steel Hoop Company	Sharon, Pa.
Sizer-Forge Company	Buffalo, N. Y.
Southern Iron & Steel Company	Birmingham, Ala.
Southern California Iron & Steel Co.	Los Angeles, Cal.
Standard Steel Works	Burnham, Pa.
Societe des Acieries d'Alexandrovsky Company	Russia
Thomas & Company, Ltd., R.	England
Trubia Arsenal	Spain
Tacony Ordnance Company	Philadelphia
Taylor Company, N. & G.	Cumberland, Md.
Tennessee Coal, Iron & R. R. Co.	Ensley, Ala.
Trumbull Steel Company	Warren, Ohio
Truder Morris Company	Eddystone, Pa.
United Alloy Steel Corporation	Canton, Ohio
Utah Iron & Steel Company	Salt Lake City, Utah
Upson Nut Company	Cleveland, Ohio
U. S. Ordnance Dept. Arsenal	Watertown, Mass.
Vickers Sons & Maxim, Ltd.	England
Wickwire Steel Company	Buffalo, N. Y.
West Coast Iron Company	San Francisco, Cal.
Wilmingham Steel Company	Wilmingham, Del.
Wood-Allan Iron & Steel Company	Philadelphia, Pa.
Worth Brothers Company	Coatesville, Pa.
West Leechburg Steel Company	Pittsburgh, Pa.
Whitaker Glessner Company	Portsmouth, Ohio
Wickwire Brothers	Cortland, N. Y.
Washburn Wire Company	Phillipsdale, R. I.
Youngstown Sheet & Tube Company	Youngstown, Ohio

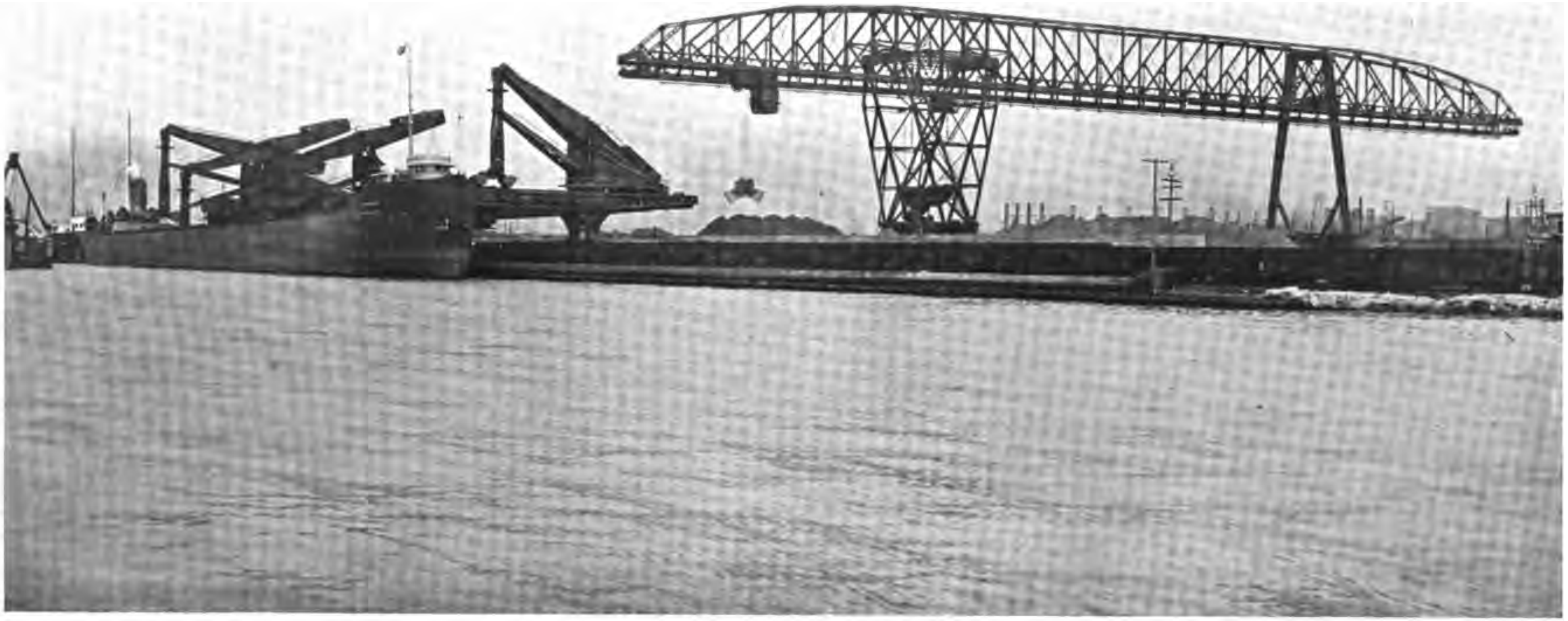


Figure 166—W-S-M ORE BRIDGE

Dock of the Ohio & Western Pennsylvania Dock Co., at Cleveland. It is the largest ore handling bridge ever constructed. It is over 612 feet long, handles a 15-ton ore bucket and covers an ore storage of over a million tons.

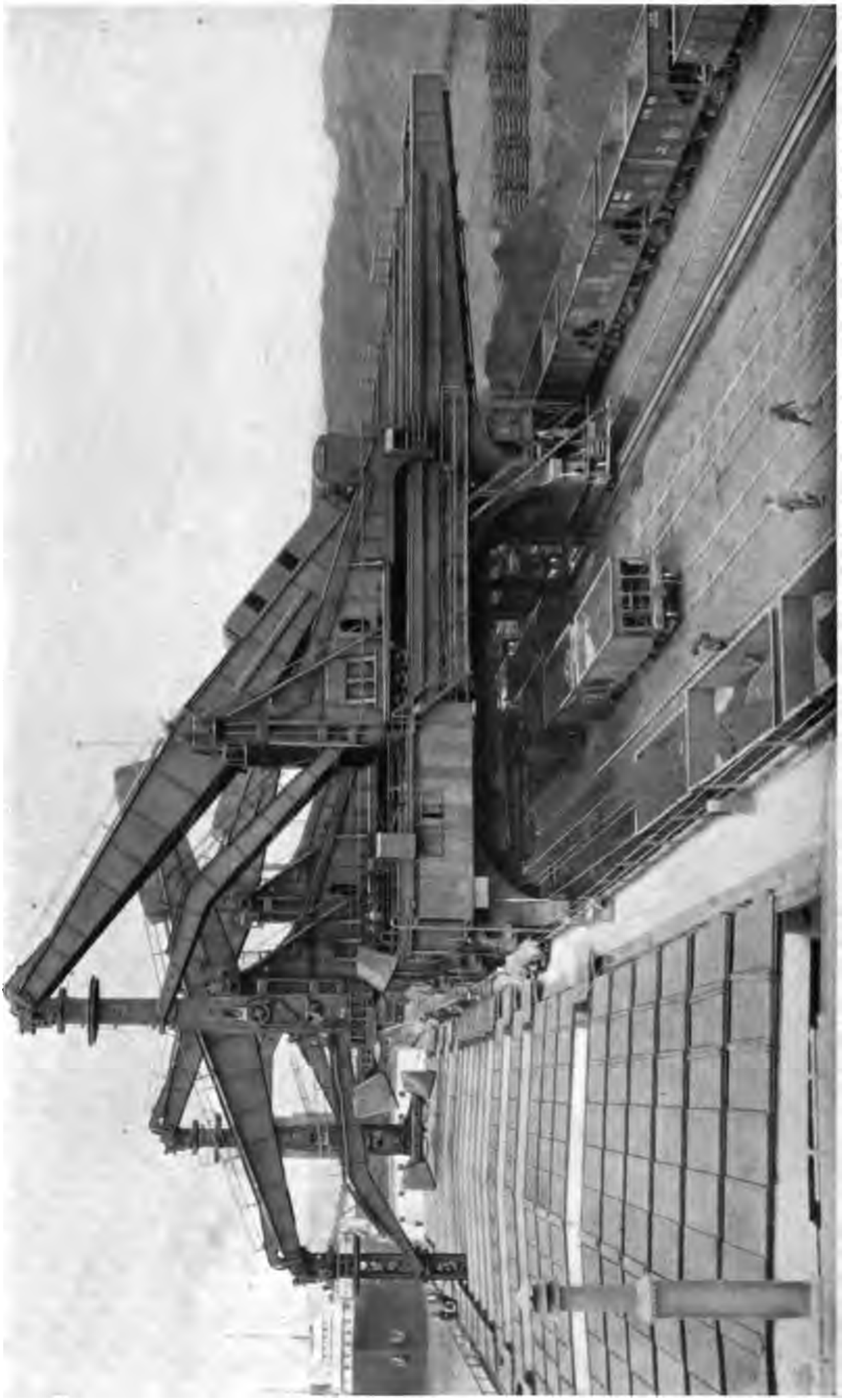
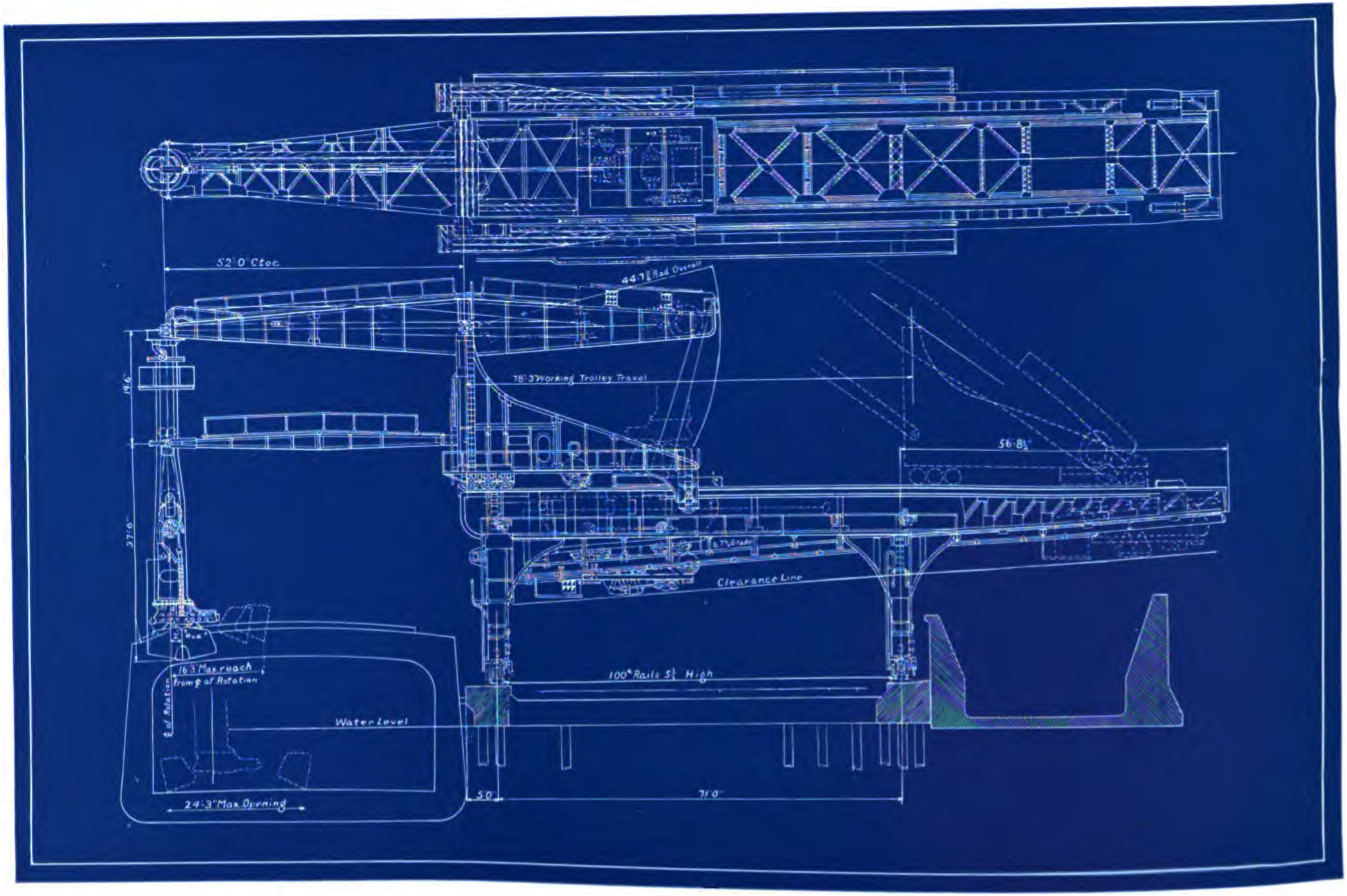


Figure 167—W-S-M AUTOMATIC ORE UNLOADER

Over fifty of these machines are in use on the Great Lakes unloading ore steamers. This view shows part of a fleet of seven W-S-M unloaders working at the dock of the United States Steel Corporation. These seven



machines have discharged 11,000 tons of ore from the steamship W. P. Palmer to railroad cars in two hours and fifty-eight minutes. Only three men are required to operate one machine. Each machine accurately weighs the ore it handles.

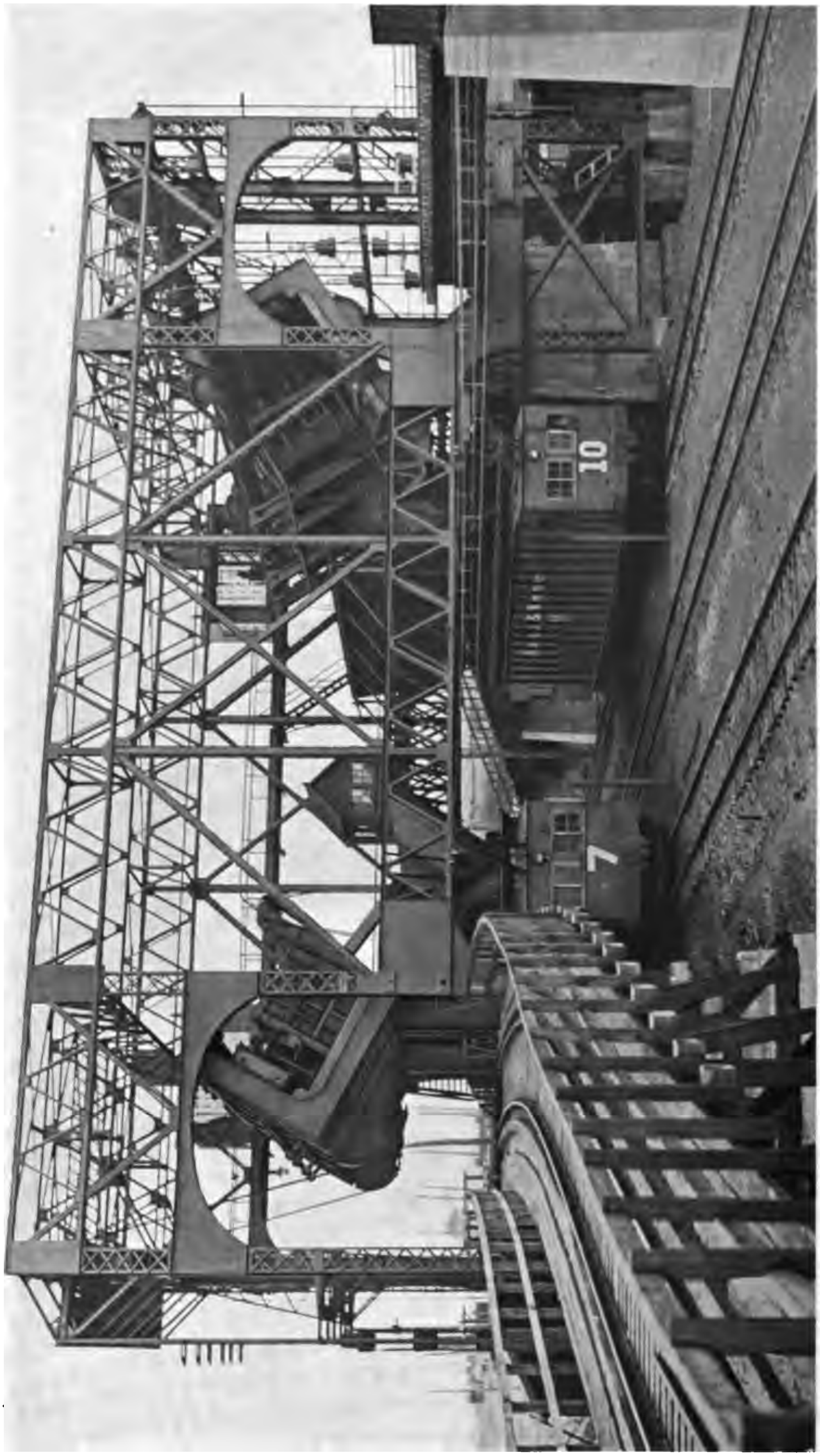


Figure 168—W-S-M DOUBLE CAR DUMPER

This view shows a double car dumper installed at the coal pier of the Norfolk & Western R. R. Co., at Norfolk, Va. These machines handle all sizes of road cars at speeds up to 30 cars an hour each.

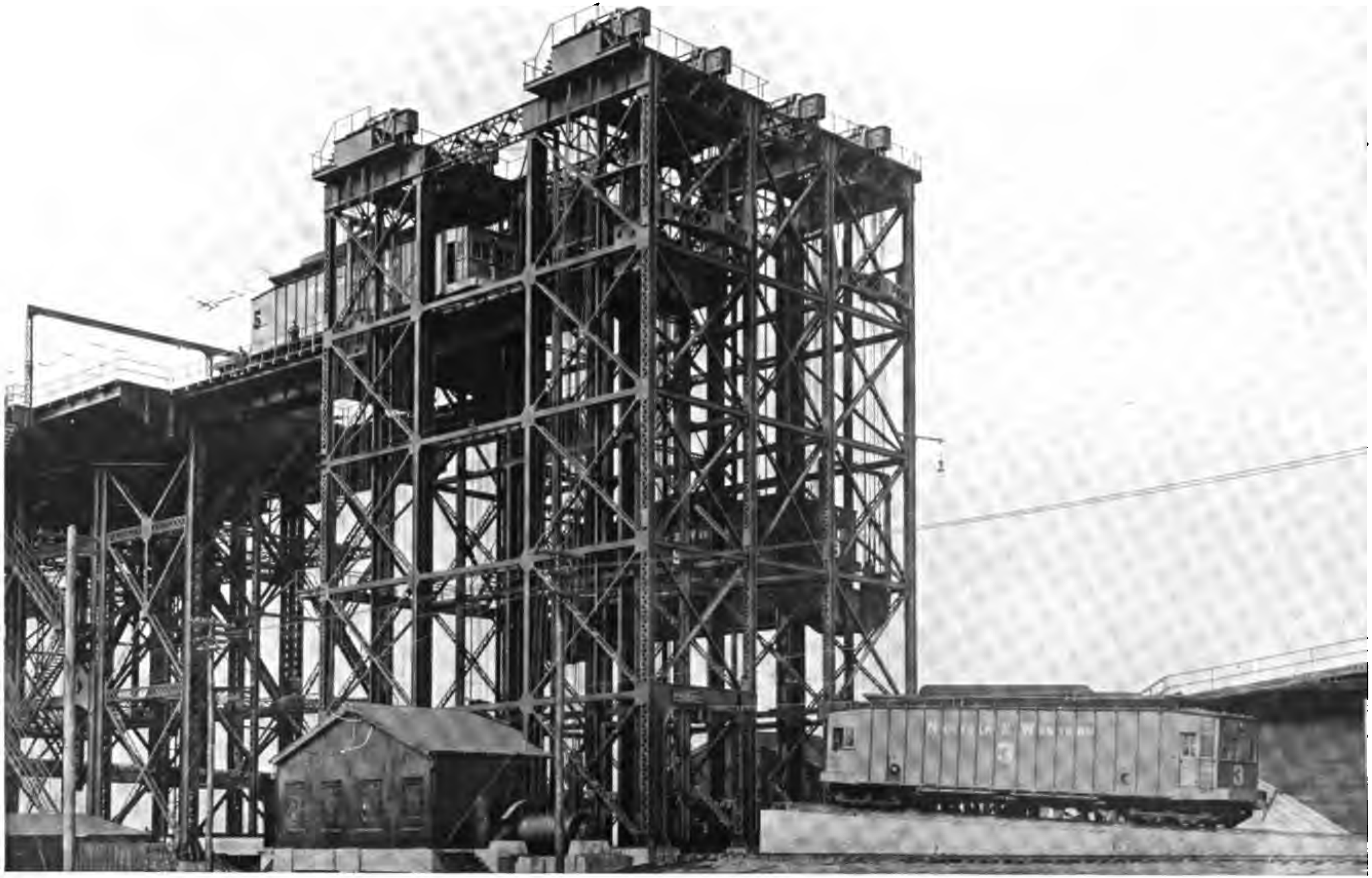


Figure 169—WELLMAN DOUBLE CAR ELEVATOR

This view shows a double car elevator constructed for the Norfolk & Western R. R. at Norfolk. It is used for hoisting 100-ton transfer cars, to the top of the pier. Each side of the elevator handles 30 cars an hour.

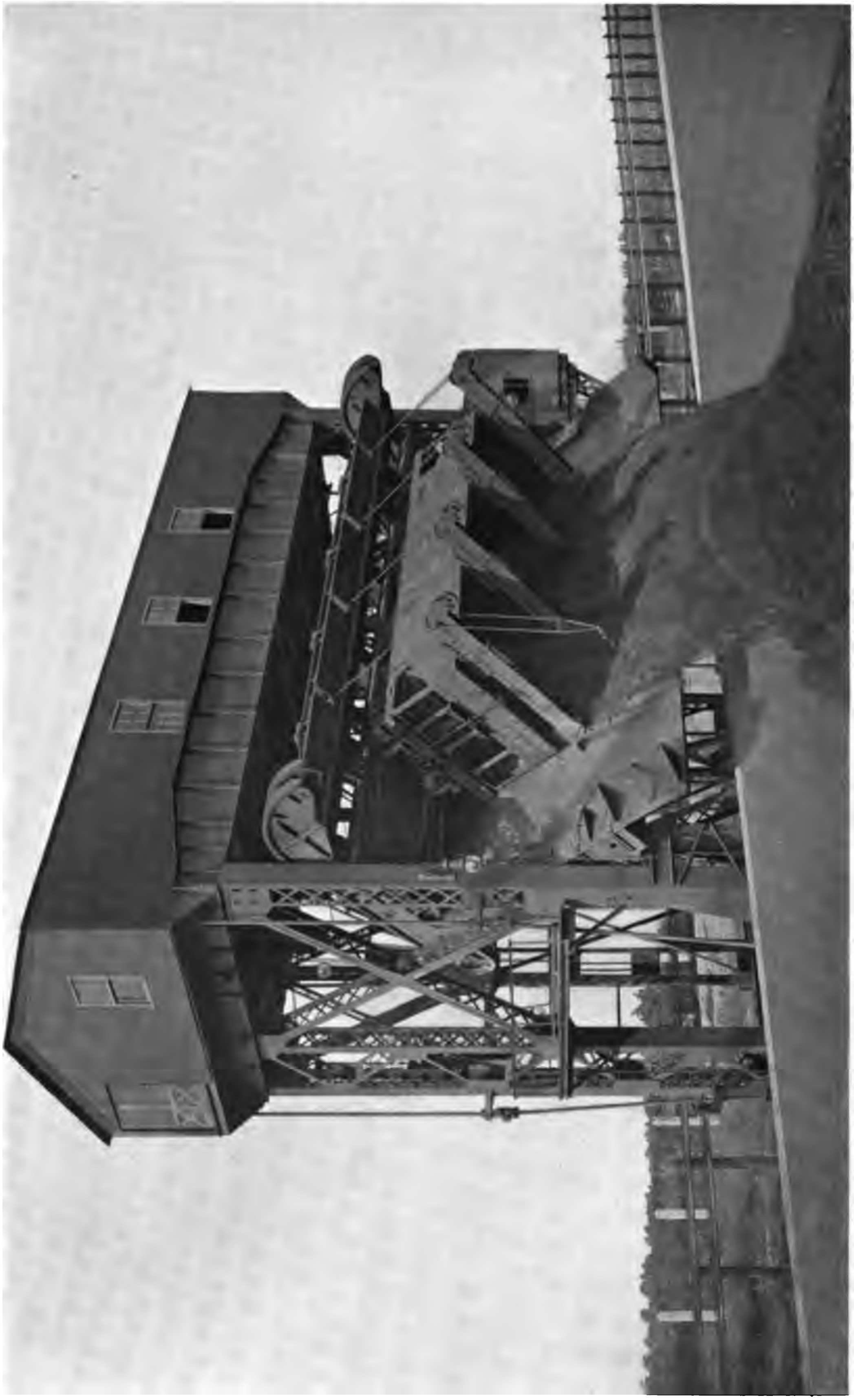
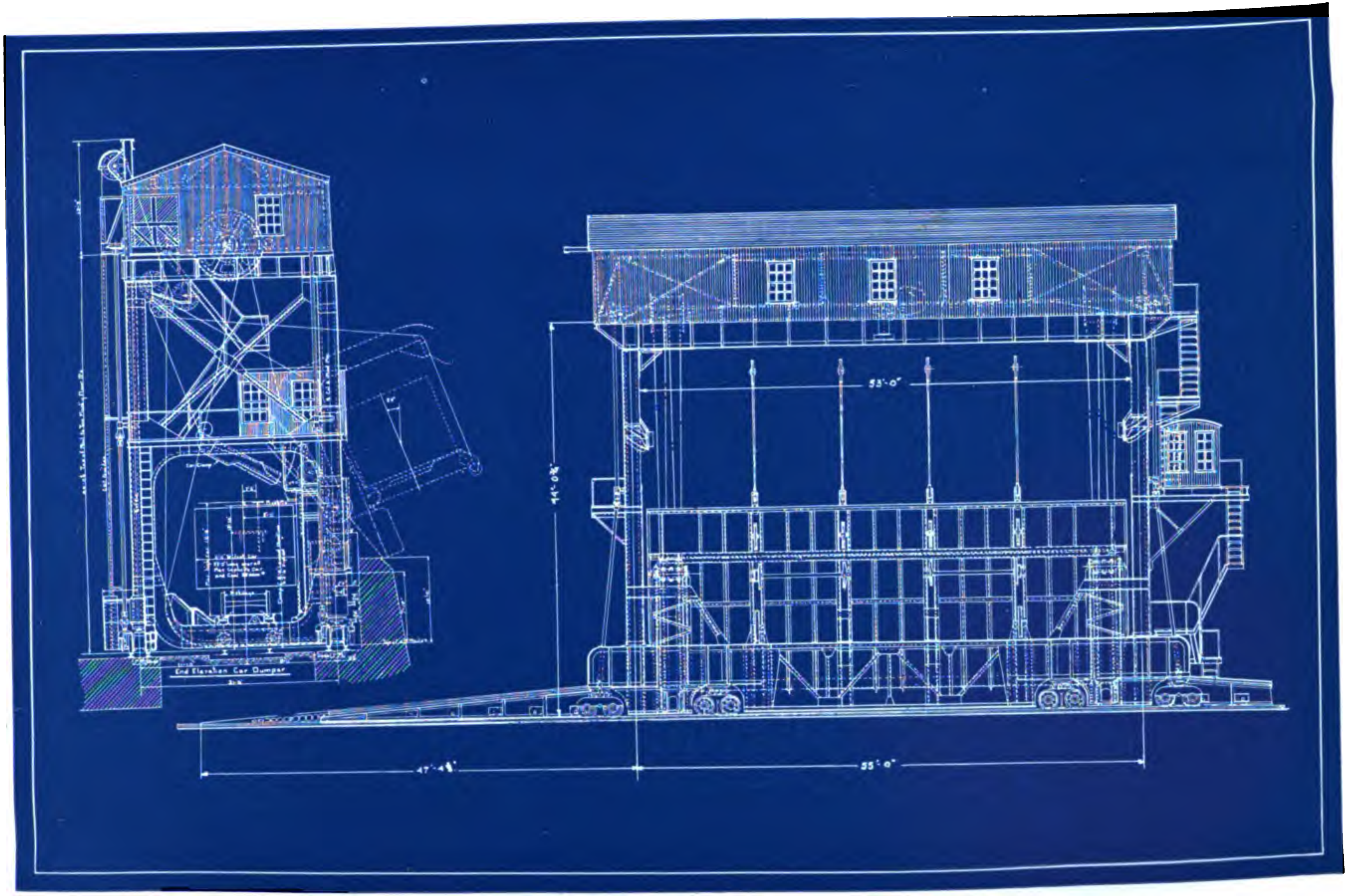


Figure 170—W-S-M MOVABLE CAR DUMPER

At some plants, conditions favor a car dumper of the movable type shown in the above view. This machine moves on trucks traversing the length of the storage yard and dumps the ore over a retaining wall. It is admir-



ably adapted for this purpose as it is possible to move the machine opposite the proper portion of the storage space, thus making the required distribution directly. Any size car can be handled at speeds up to 30 cars an hour. The inclined approach and discharge tracks are attached to the machine and travel with it.

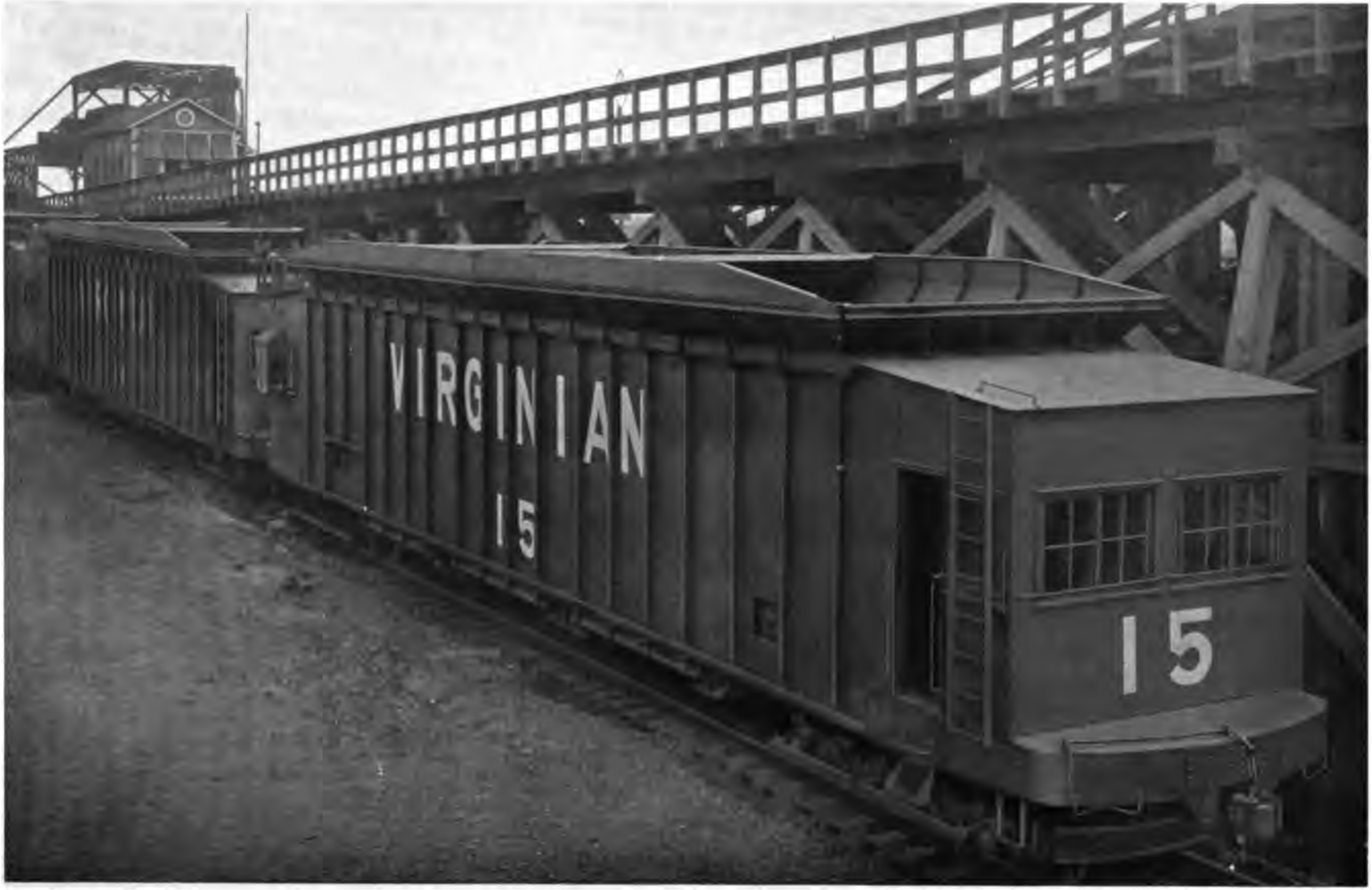
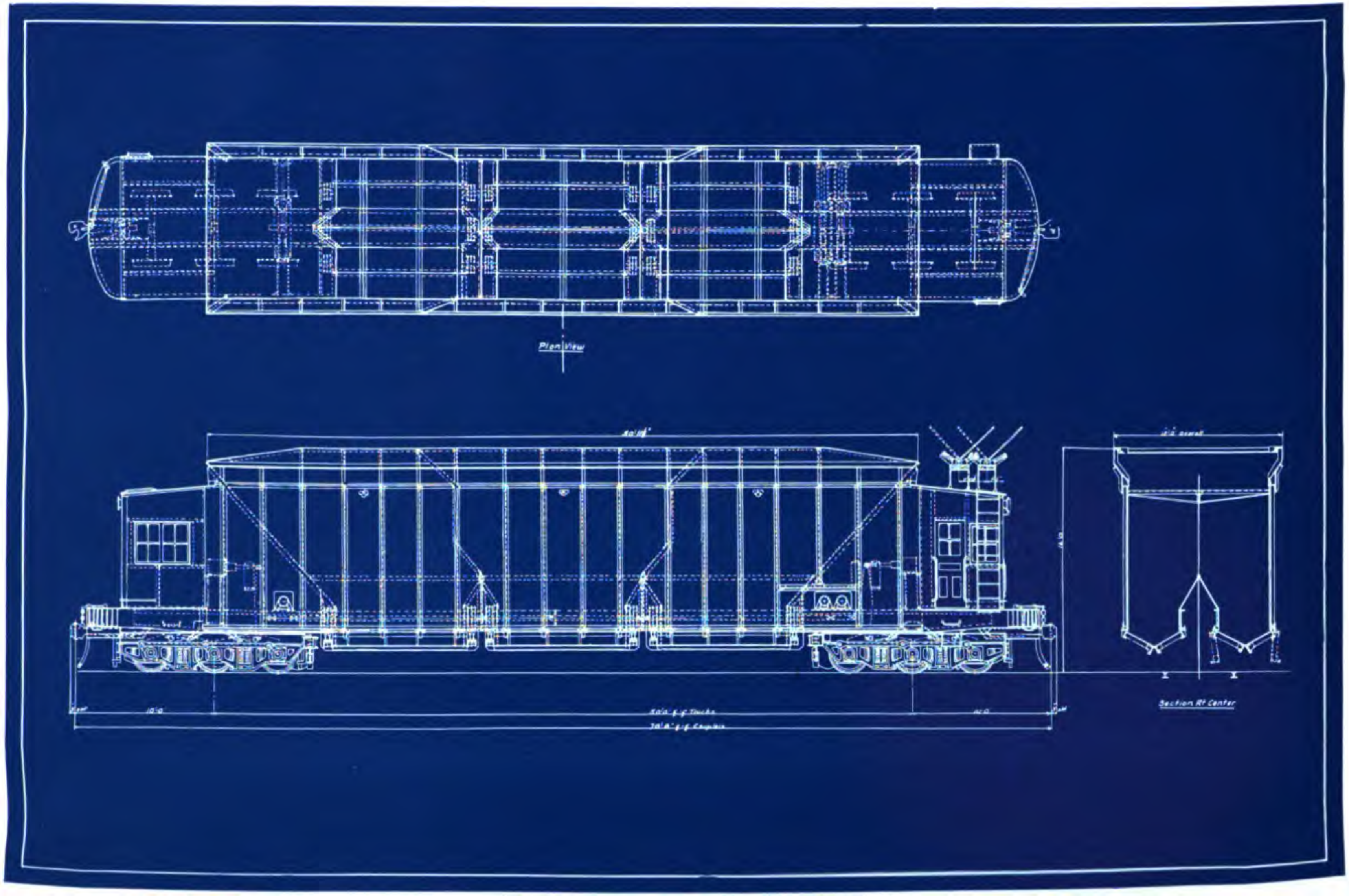


Figure 171—W-S-M TRANSFER CARS

At the plant of the Virginian Railway Co., at Sewalls Point, Va., the road cars are dumped into special, bottom dump transfer cars, which are elevated to the top of the pier and discharge their contents into loading pockets.



The above view shows one of these special cars. The hopper capacity is 120 tons of coal, and this is divided into three compartments each equipped with outlet gates. The car is motor driven by two 60 hp. motors, one applied to each of the six-wheel trucks. All motions of the gates and car are controlled from the operator's cab at one end.

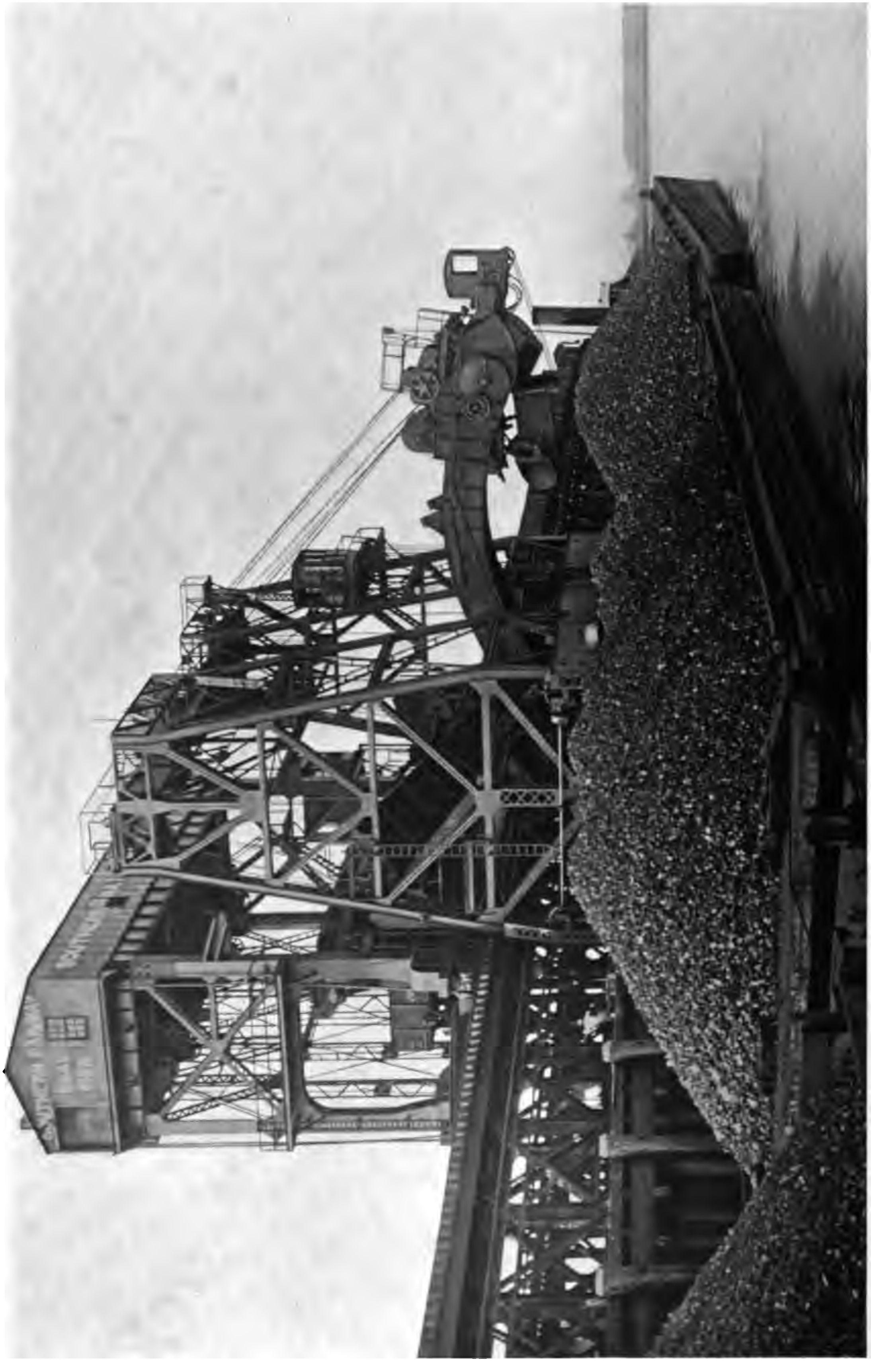
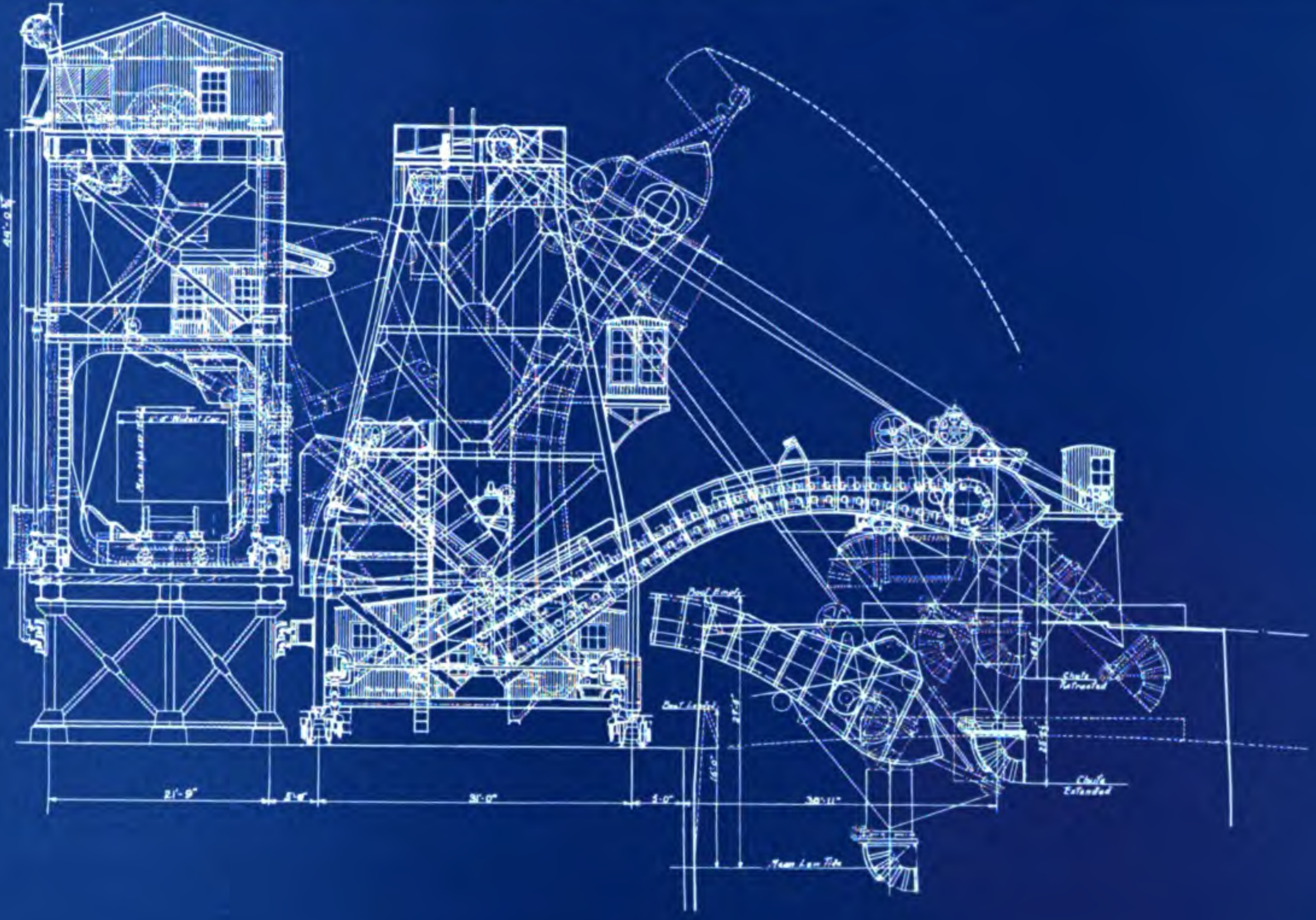


Figure 172—W-S-M CAR DUMPER AND COAL LOADING TOWER

The coal handling equipment of the Southern Railway Co., at Charleston, S. C., consists of a movable car dumper and loading tower. The car dumper which is similar to the one shown on page 352, dumps the coal from road



cars into a hopper of the loading tower. From the hopper coal discharges through a gate onto a steel conveyor in a hinged boom. The conveyor transfers the coal to the telescope chute which distributes it into the boat. When out of service the boom is hoisted. This machine handles either cargo or bunker coal and has a capacity of 3,000 tons an hour.

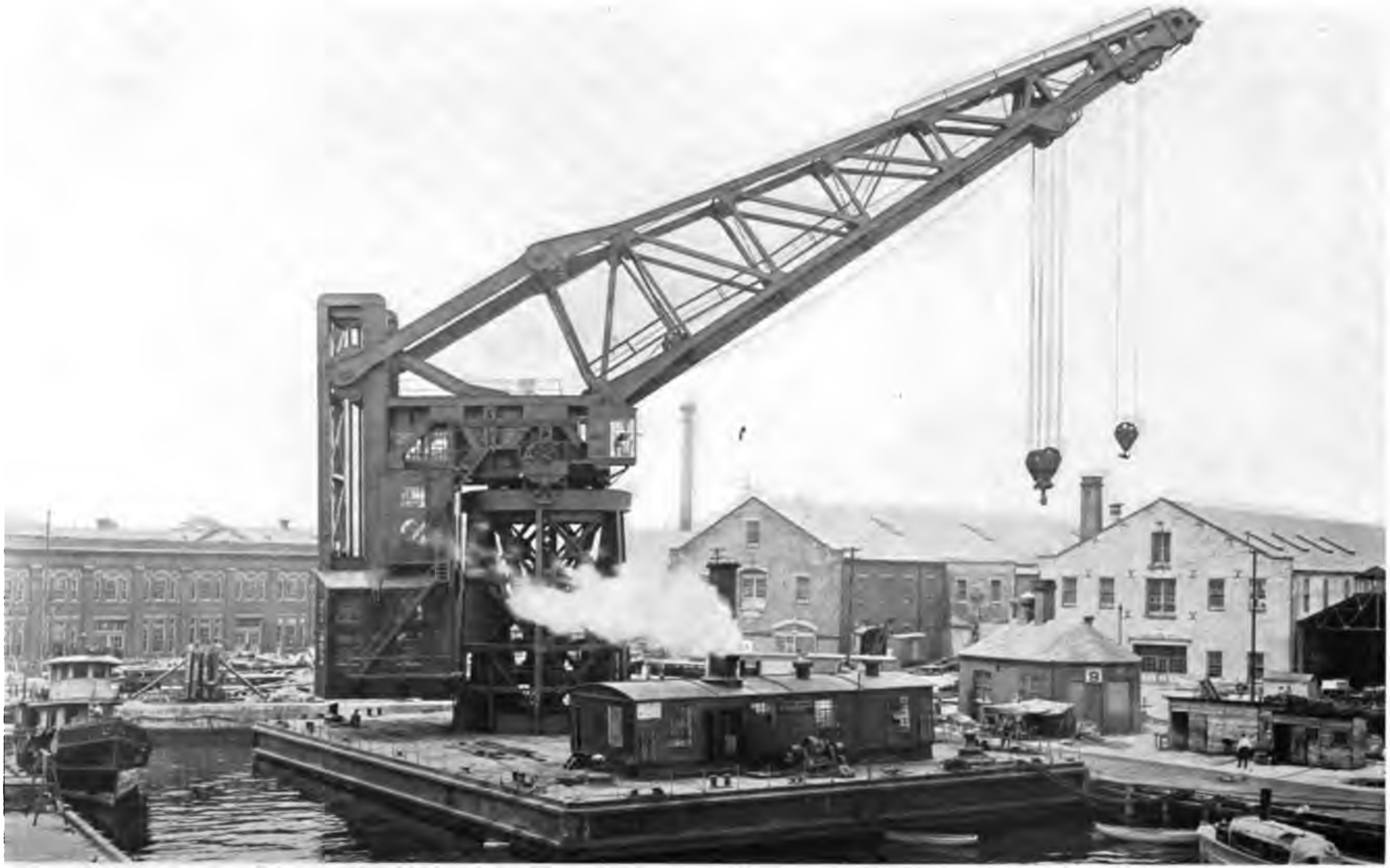
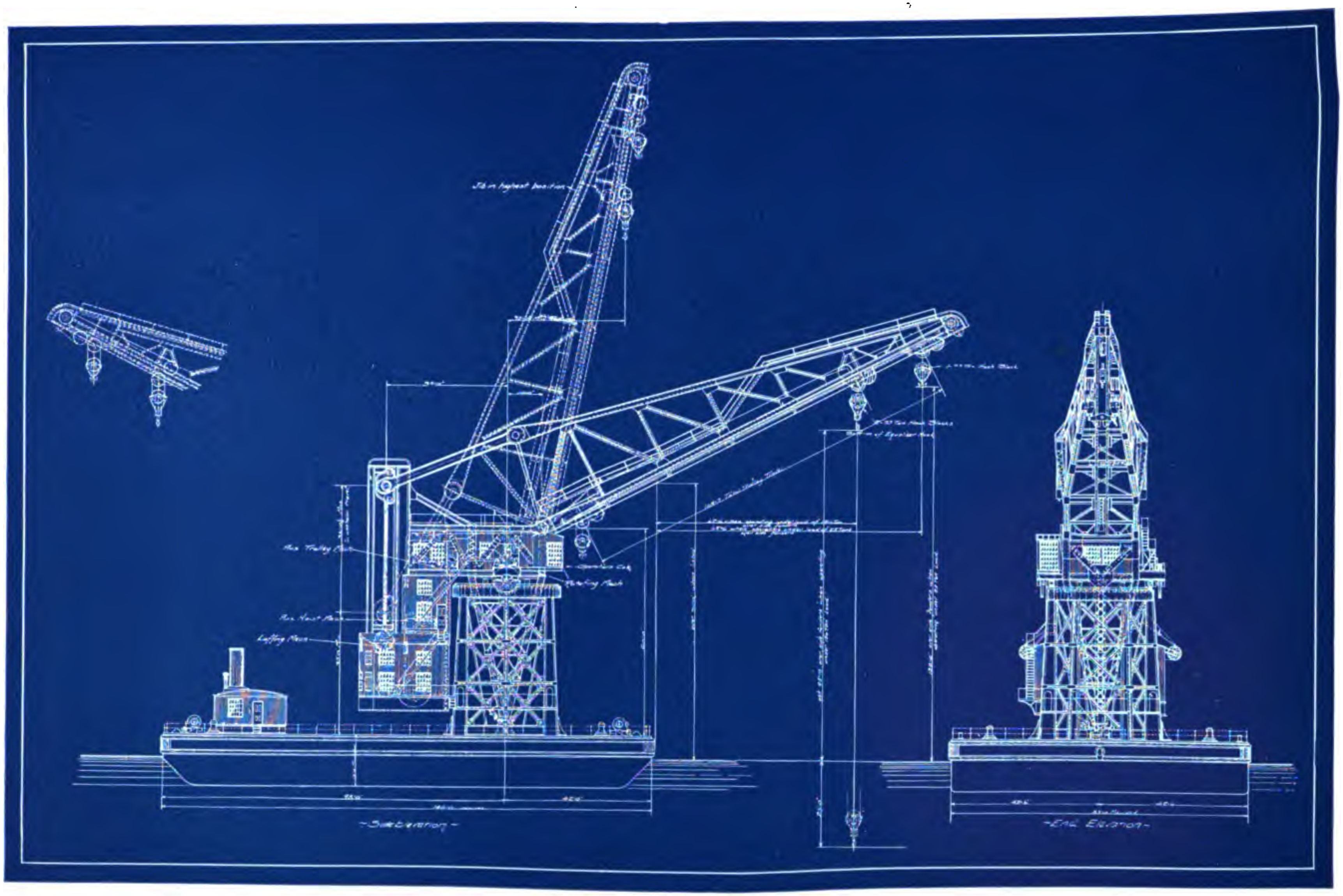


Figure 173—W-S-M PONTOON CRANE

The electrically operated floating cranes in the U. S. Navy Yards at Norfolk and Mare Island are the largest machines of this type ever built in the United States. The revolving superstructure is mounted on a steel pon-



toon 85 feet wide and 140 feet long. The lifting equipment consists of two 75-ton hook blocks fixed on the jib and a 25-ton movable auxiliary hook lock. The crane will handle 150 gross tons at a working radius of 105 feet, and under test has handled a weight of 403,200 pounds. These cranes are used for fitting out ships and for handling heavy machinery.

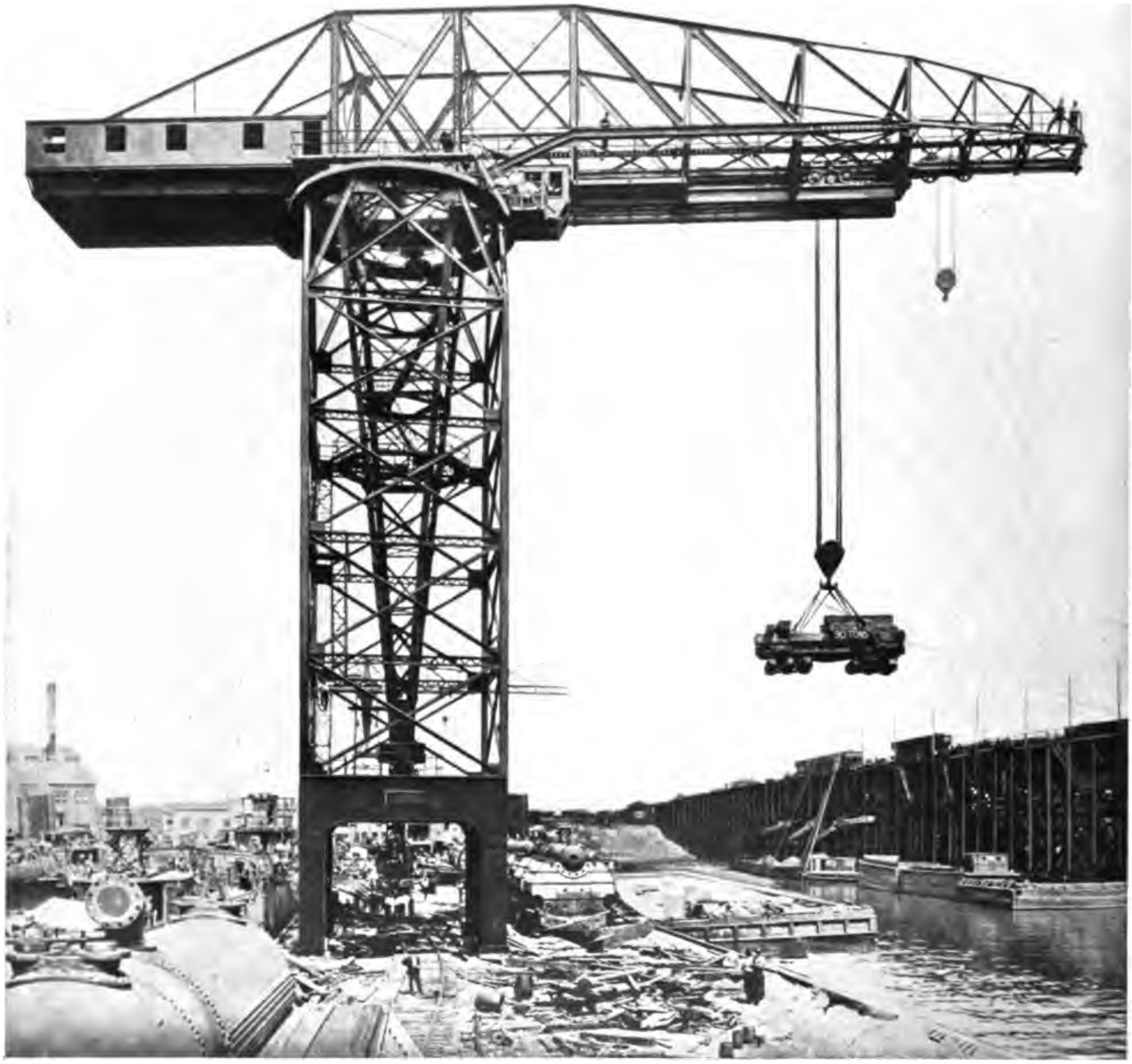


Figure 174—W-S-M SHIPYARD FITTING OUT CRANE

This 75-ton electrically operated stationary hammerhead revolving fitting out crane is shown under test load at the shipyard of the Wm. Cramp & Sons Ship and Engine Building Company.

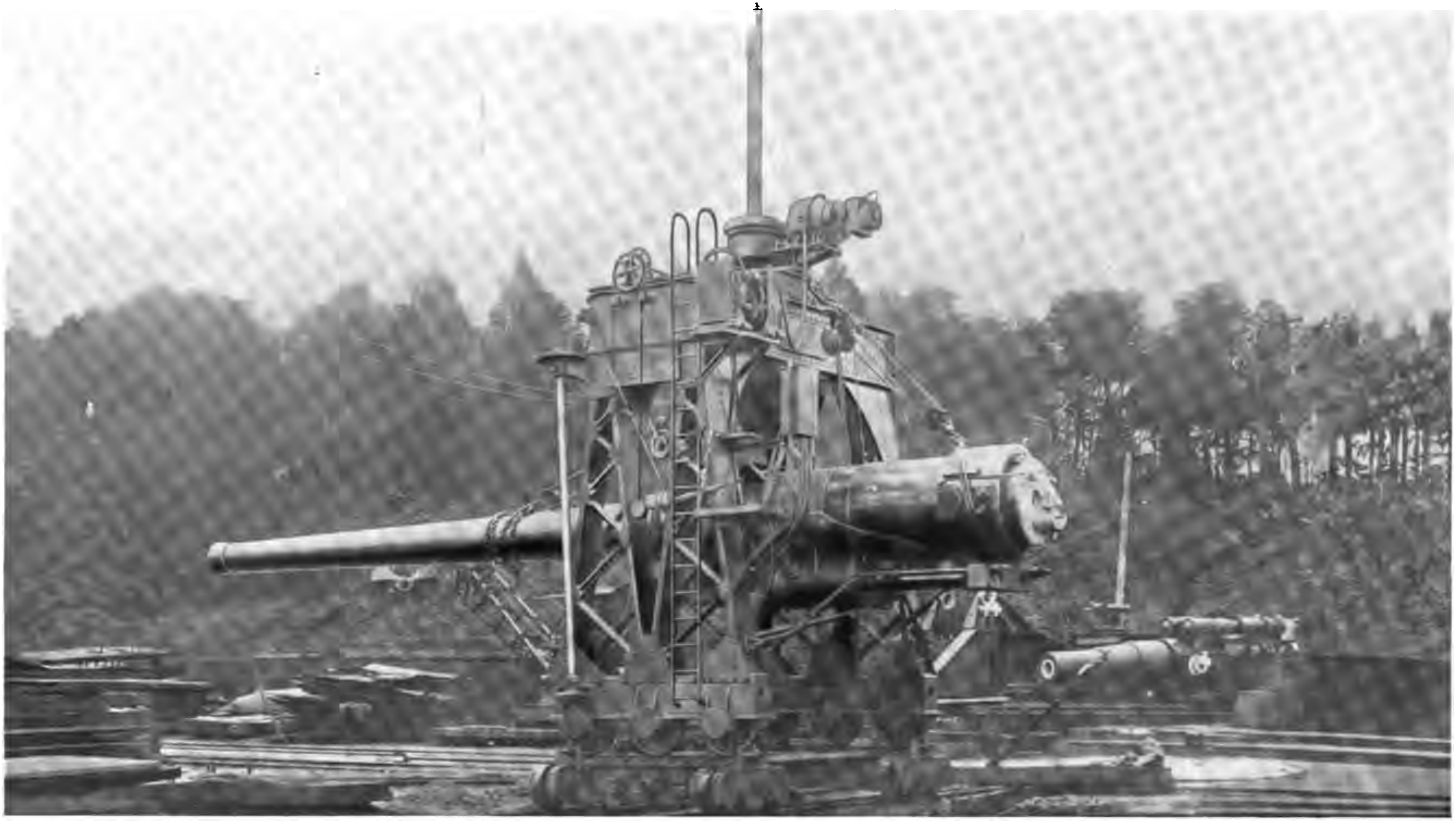


Figure 175—W-S-M GUN HANDLING GANTRY CRANE

Special Gantry crane designed and built by the Wellman-Seaver-Morgan Company for the United States Government. It is used at the Indian Head Proving Grounds for moving heavy guns.

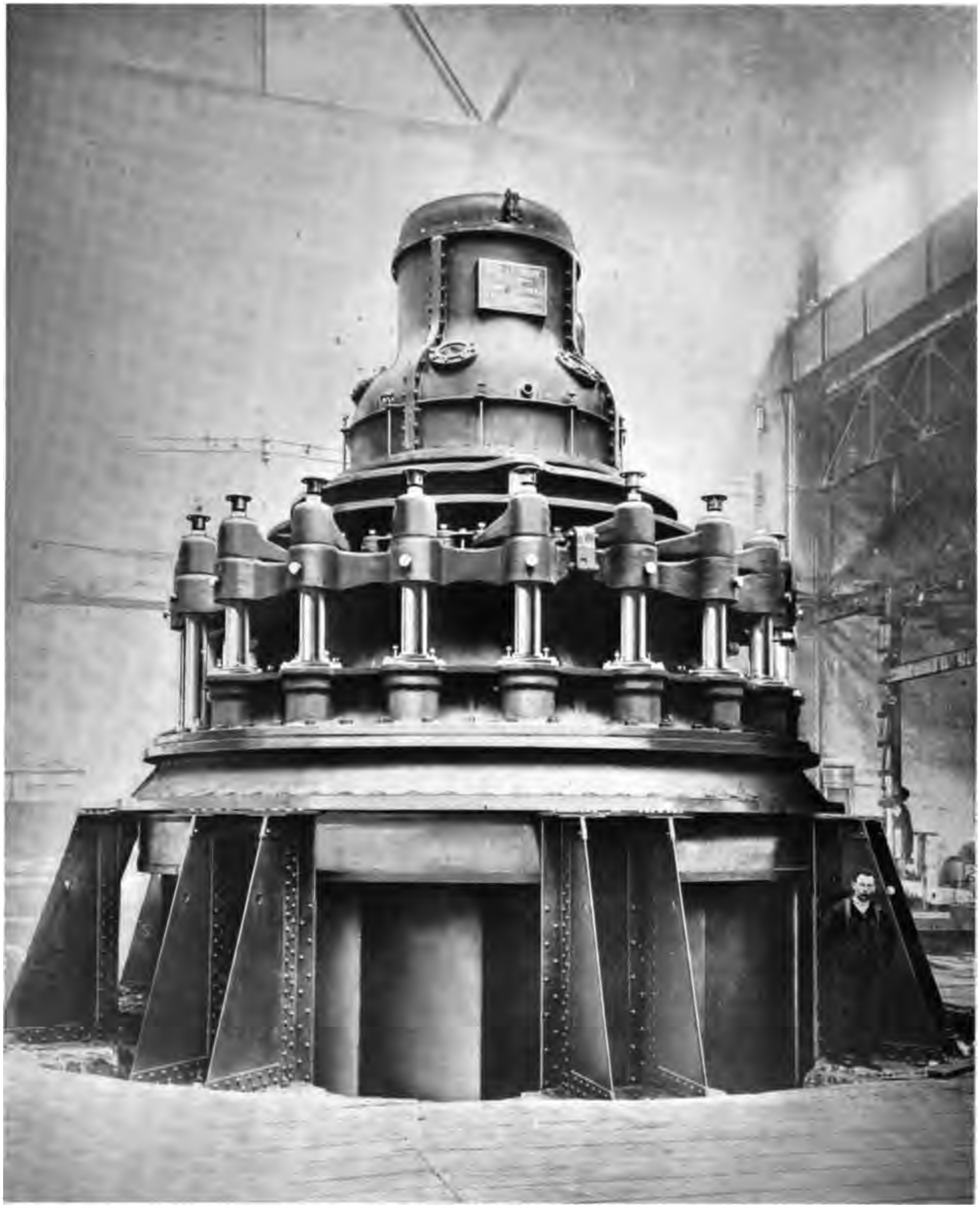
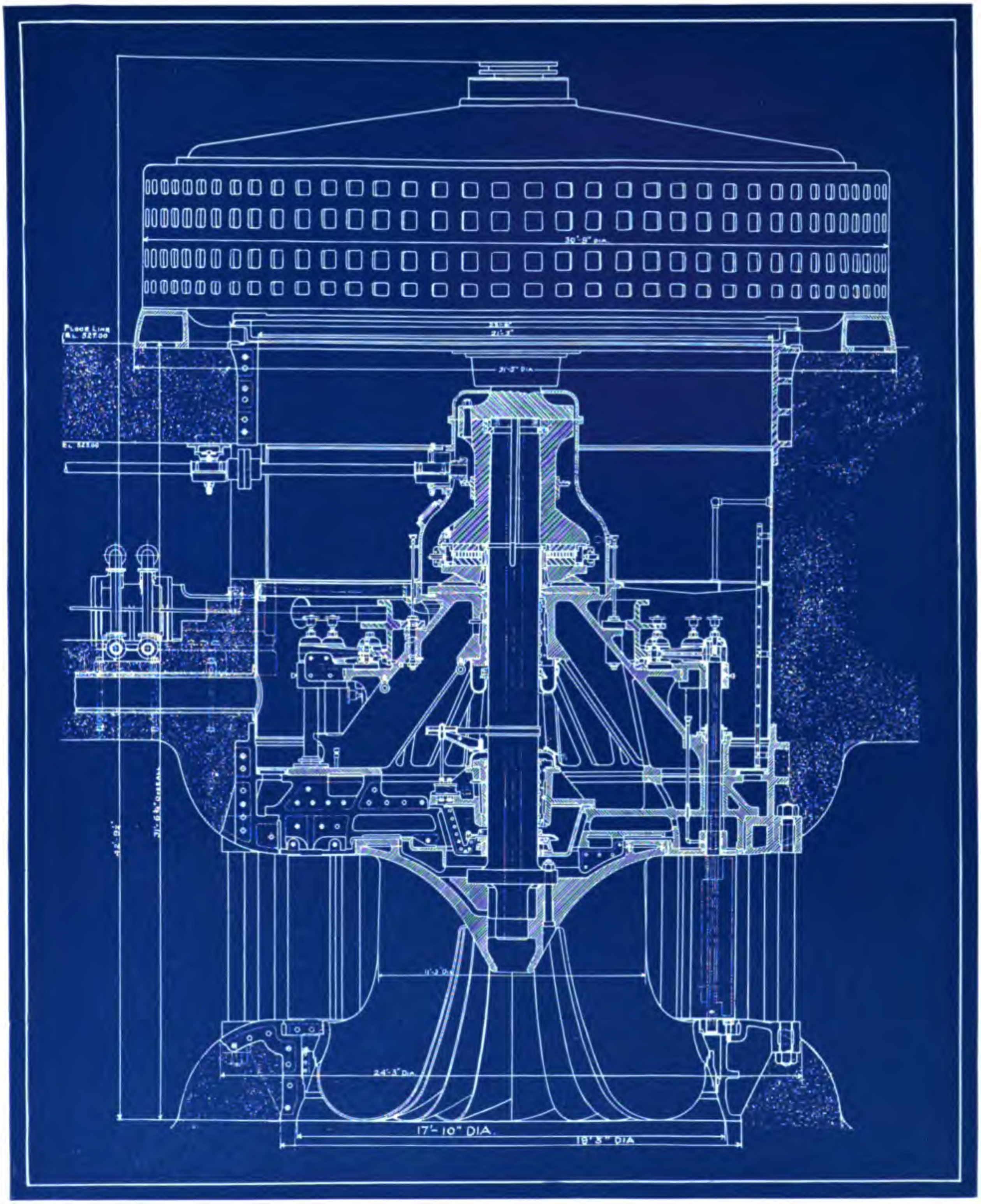


Figure 176—W-S-M TURBINES AT KEOKUK

There are seven W-S-M main unit turbines and two W-S-M exciter turbines installed at the Keokuk plant of the Mississippi River Power Company. The blueprint gives the sectional elevation of one W-S-M 10,000 hp. turbine which drives a 9,000 kvs.,



11,000 volt alternator. The normal head on the turbines is 32 feet, the maximum head 39 feet, and the minimum 20 feet. The turbines cover this range of head at a constant speed of 57.7 rpm., the output varying from 6,000 hp. to 15,000 hp.

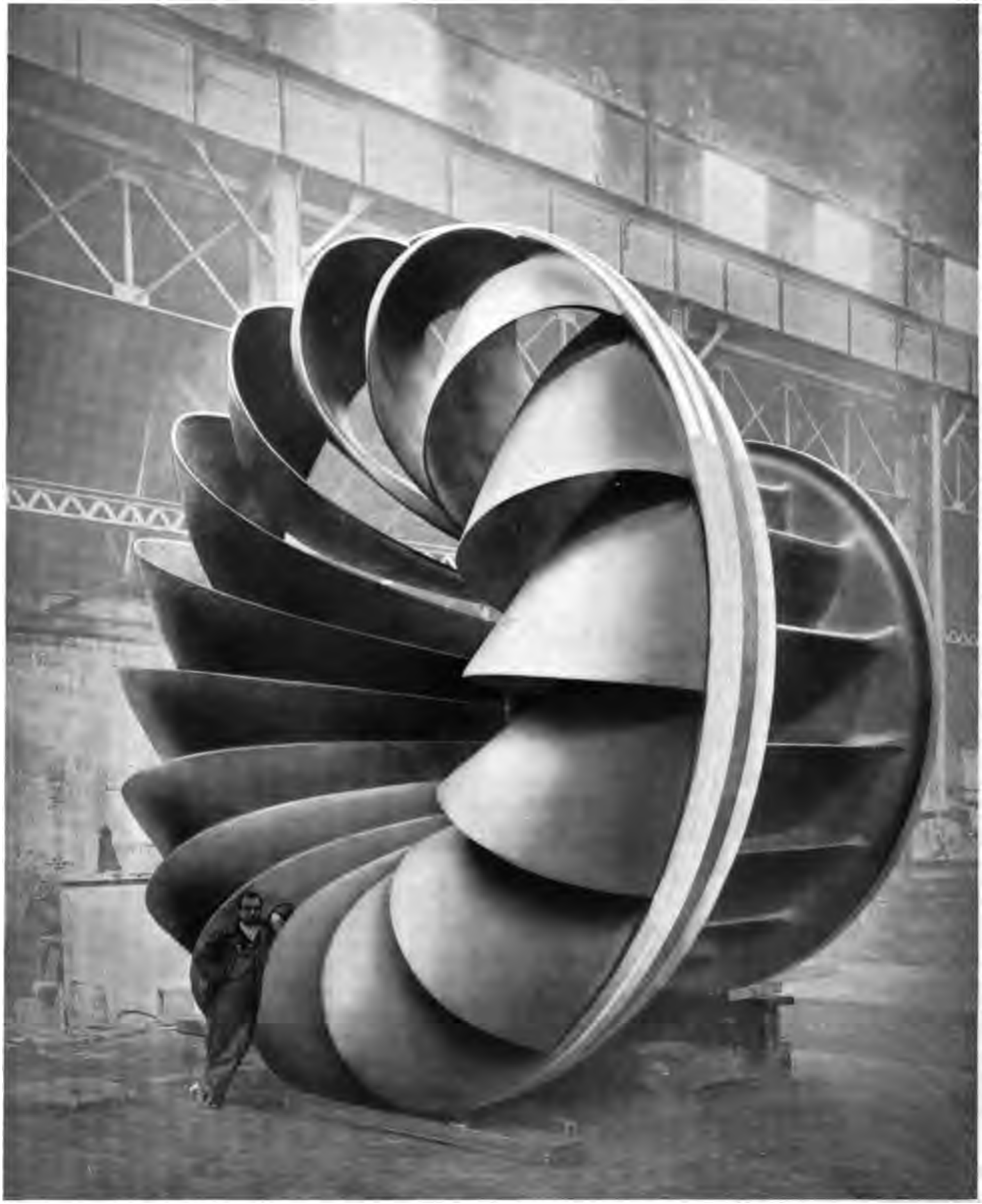


Figure 177—RUNNER FOR 10,000 H. P. TURBINE
for the Mississippi River Power Co., Keokuk, Iowa. Built in one piece. Weight 130,000 pounds.

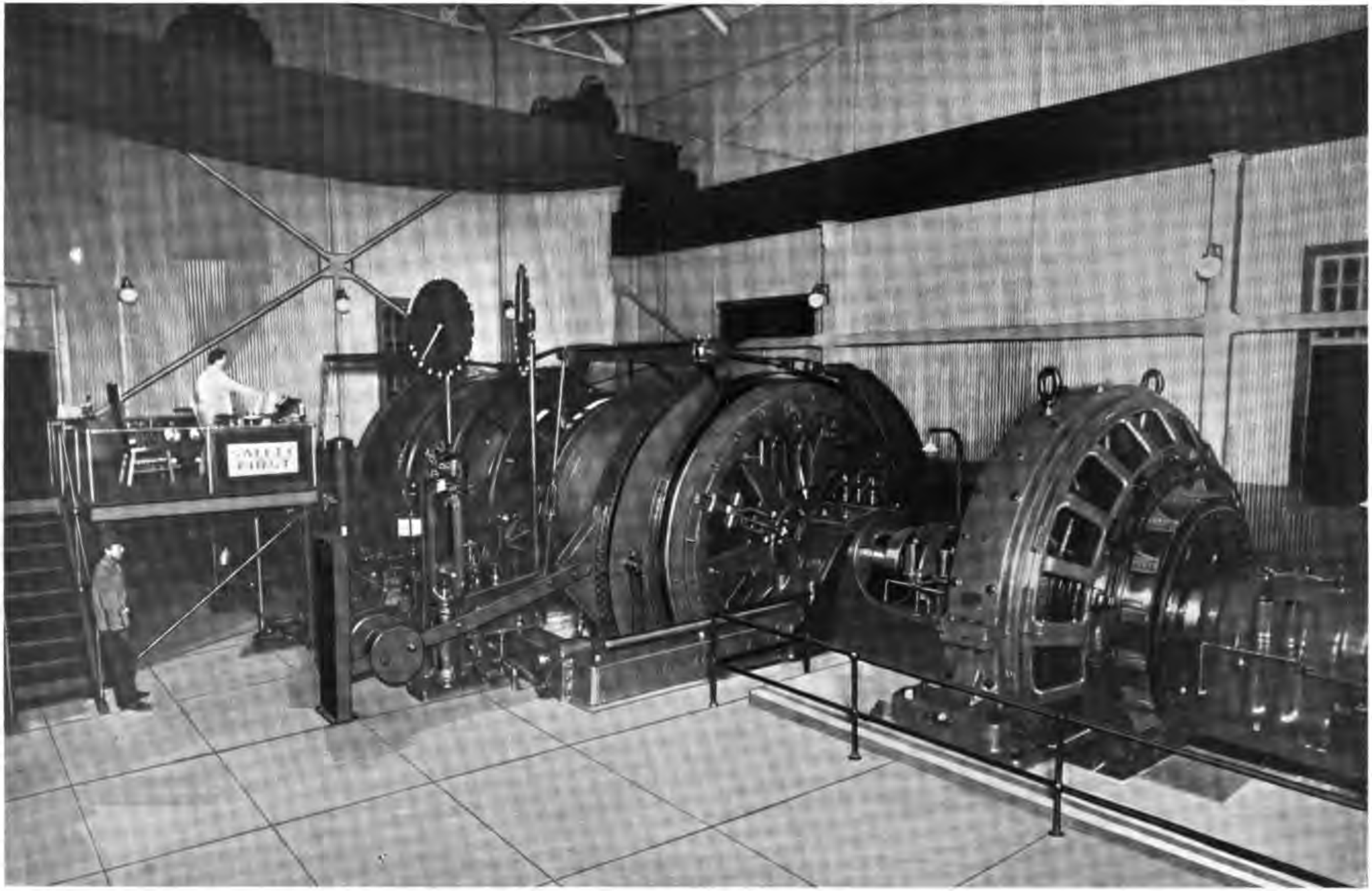


Figure 178—WELLMAN DOUBLE DRUM FIRST MOTION HOIST

Installed at the Green Mountain Shaft of the North Butte Mining Company. This is the largest first motion electric hoist in the United States. It will handle a 42,000 lb. load with the motor making only 1 rpm.

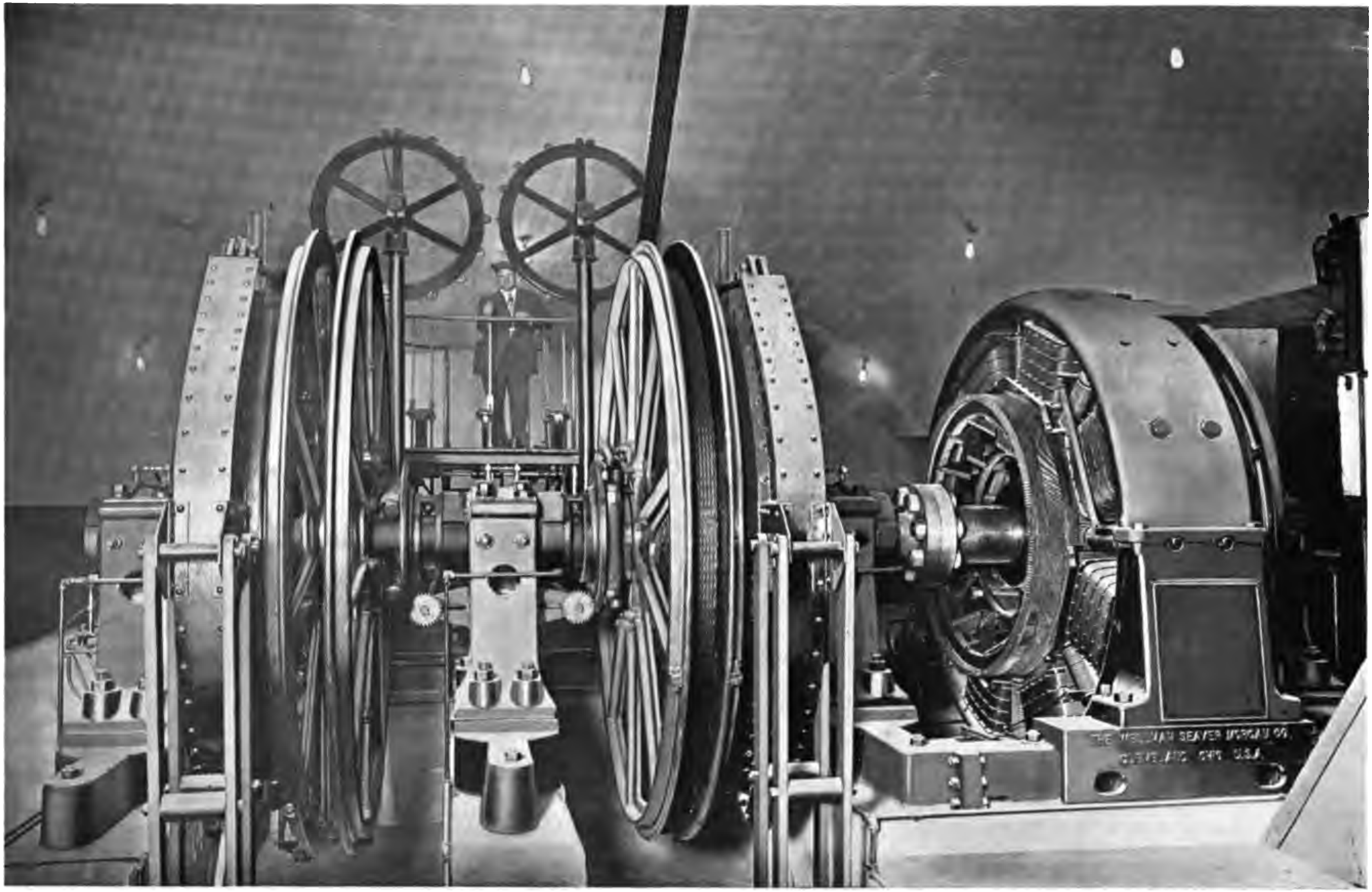


Figure 179—WELLMAN FLAT ROPE HOIST

Installed 1800 feet below a mountain top and two miles in the mountain at the Silver King Coalition Mines. This is a double drum first motion electric hoist.

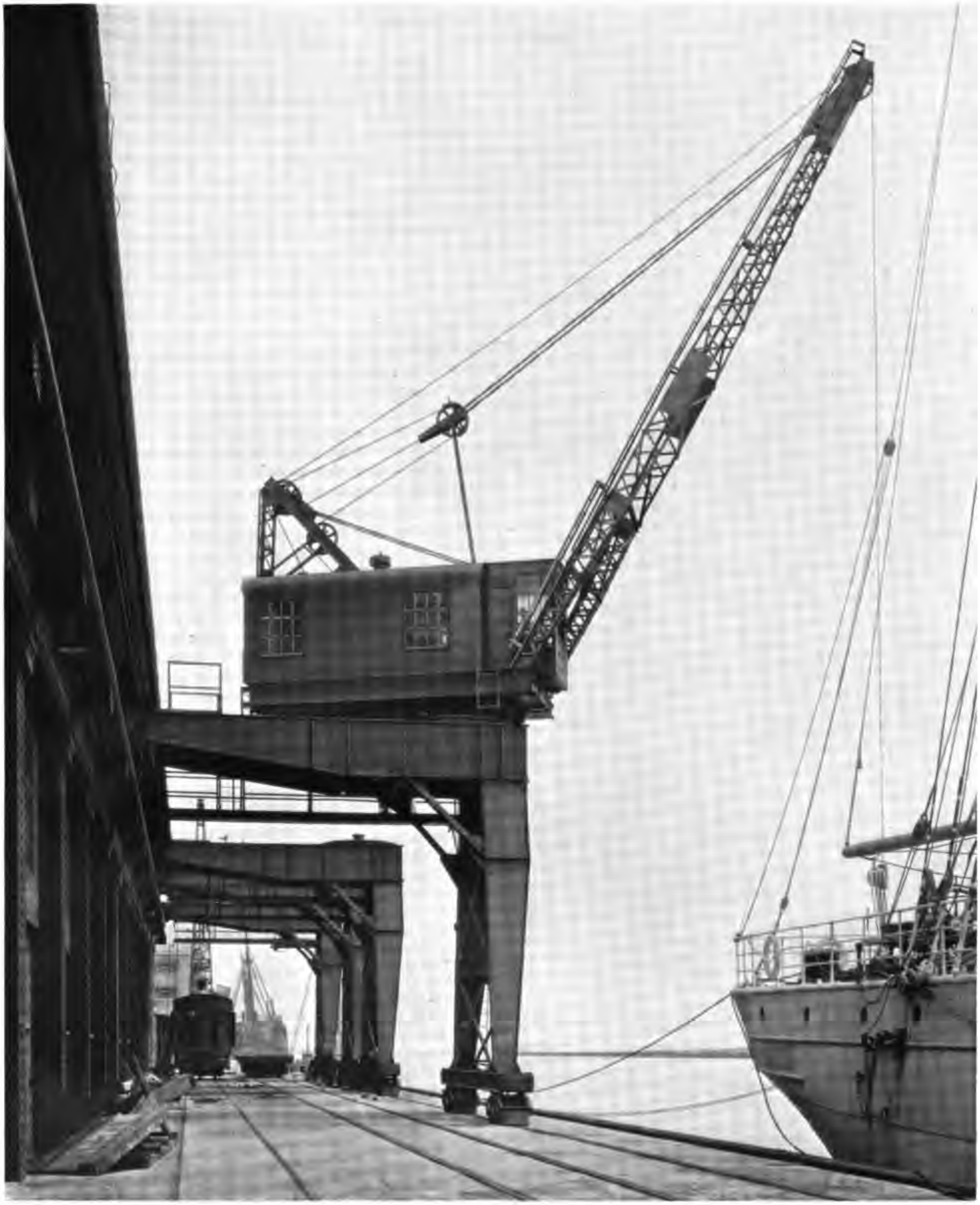


Figure 180—W-S-M DOCK CRANES, U. S. ARMY SUPPLY BASE, BOSTON

The Wellman-Seaver-Morgan Company has recently installed four semi-portal bridge type cranes at the U. S. Army Supply Base, Boston, to handle freight to and from ships.

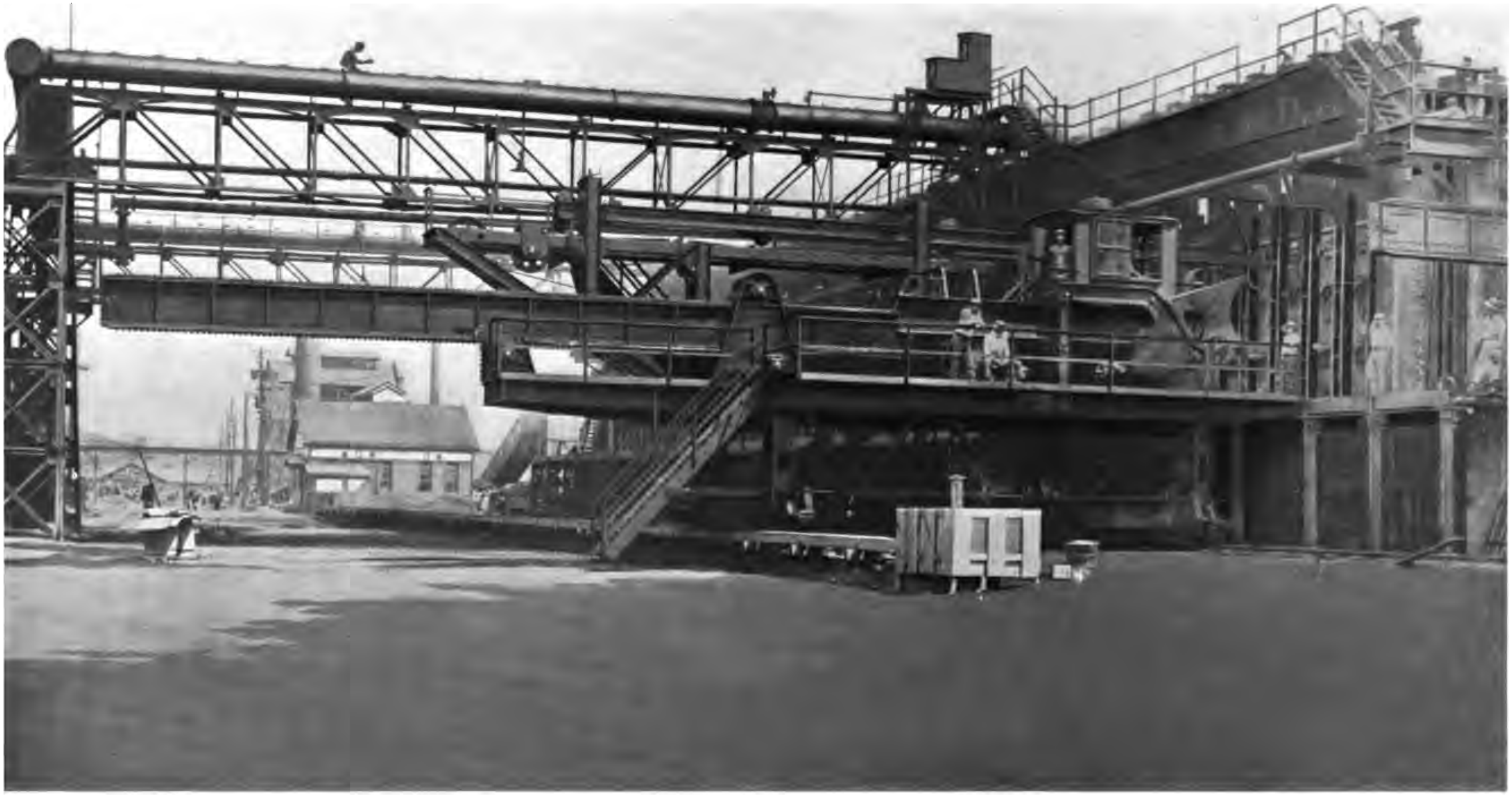
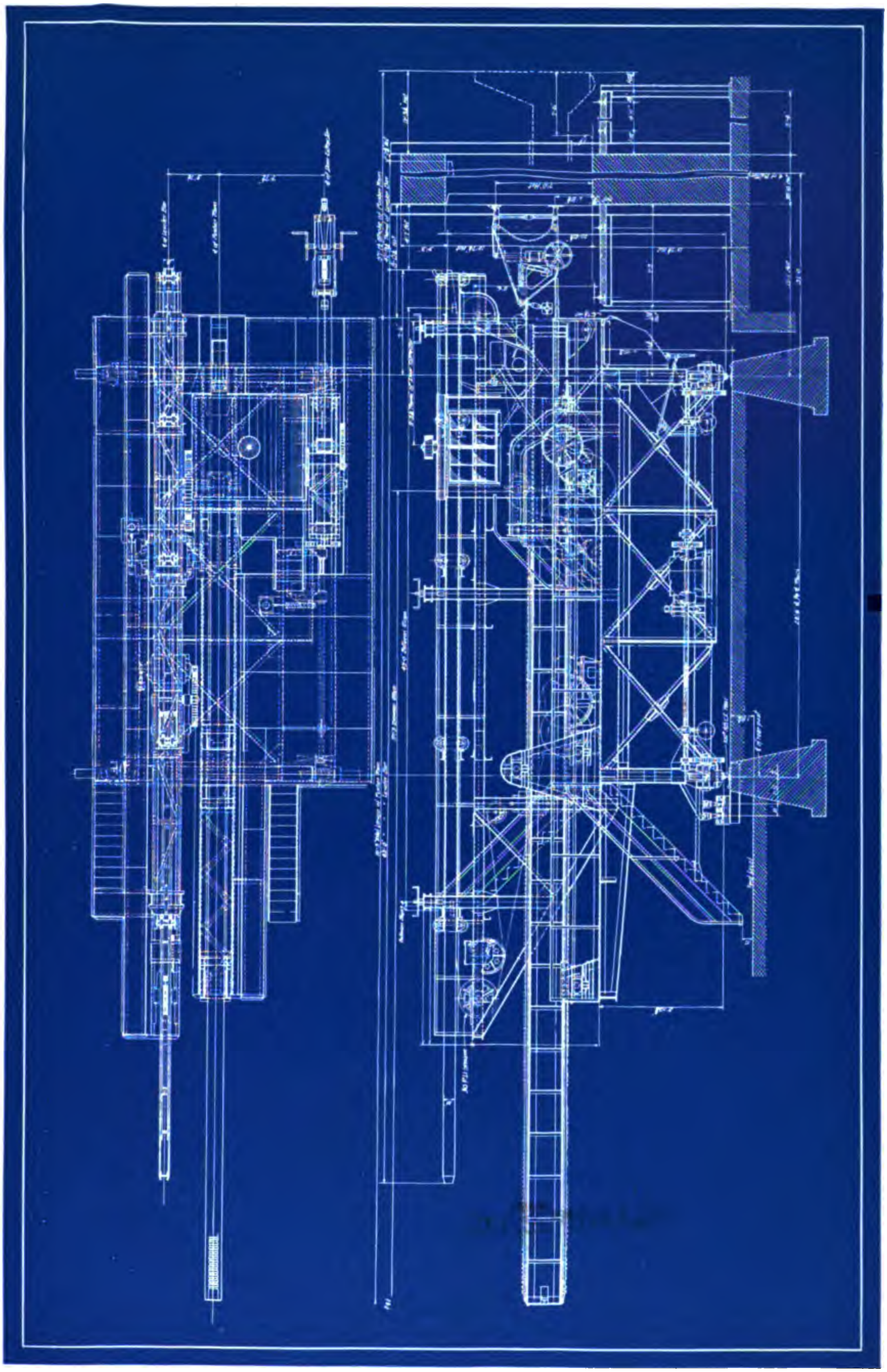
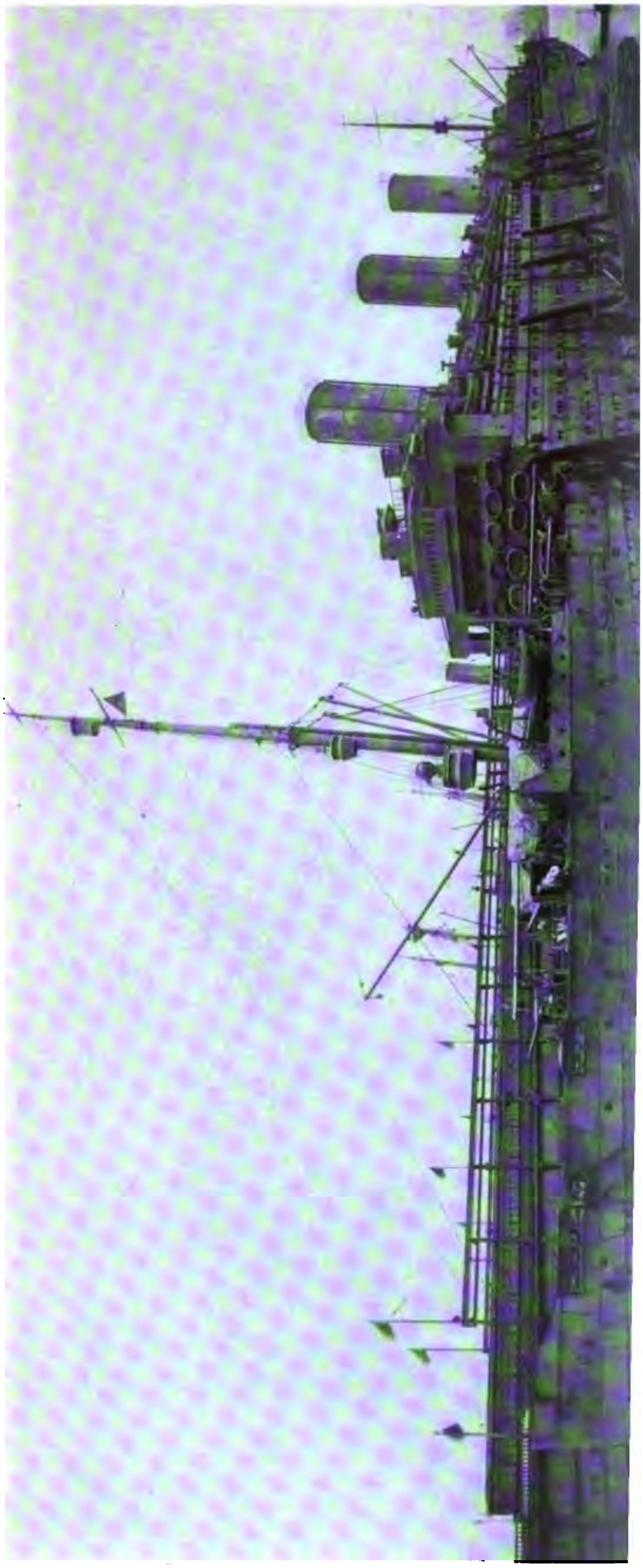


Figure 181—W-S-M COMBINED COKE PUSHER, COAL LEVELER AND DOOR EXTRACTOR

The combined coke pusher, coal leveler and door extractor shown in this illustration represents the latest by-product coke oven practice. It removes and replaces oven doors, levels the coal and pushes the coke from the



ovens, all of these motions being under the control of one operator. One machine has capacity to handle about 100 ovens. The by-product coke oven is fast replacing the beehive type as it not only permits of mechanical handling but saves a great percentage of the by-products of the coal wasted in the beehive ovens.



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Time of Heat
Tool Steel
Triplex Proce
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